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A TECHNICAL AND ECONOMIC EVALUATION OF WOOD CONVERSION PROCESSES:
VOLUME II, APPENDICES

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Preface

This is the final report under Energy, Mines and Resources Canada (EMR) contract no. 23283-8-6091 entitled " A Technical and Economic Evaluation of Wood Conversion Processes". The report signifies the completion of all tasks of the project. The project was composed of four parts:

I. A complete technology review report covering the bioconversion of wood to ethanol

II. A report defining the approach and evaluation techniques used in the study

III. An engineering analysis of the Iogen process and development of a base case process design and economic performance estimates for a 1000-tonne-per-day ethanol facility

IV. Construction of a process simulation model configured on the base case design, using Lotus 1-2-3 software as the modelling medium

The purpose of the project was to provide EMR with a technical and economic assessment of the Iogen wood-to-ethanol process; to develop a simulation model for the process that is usable by government and private sector managers interested in the technology; and to define evaluation criteria to support forecasting future process improvement and associated economic consequences.

The final report will be furnished as a public document and be available from the Efficiency and Alternative Energy Technology Branch of EMR. Copies of the Lotus 1-2-3 based process simulation model will also be available on diskette.

Abstract

The primary purpose of this project was to provide Energy, Mines and Resources Canada (EMR) with a technical and economic assessment of the Iogen wood-to-ethanol bioconversion process. The evaluation technique involved developing a computer simulation model of the process using the Lotus 1-2-3 spreadsheet program. The simulation model was based on an engineering analysis of the process, complete with heat and material balances and a preliminary economic assessment.

The computer model was used to run sensitivity analyses for the process and to estimate the parameters with significant economic impact and promise for future improvement to the process economics. The most important parameters were then used in Monte Carlo simulations to estimate the potential for future improvements and to assess the commercial potential of the process. Finally, the process was subjected to a second-law analysis. The second-law analysis assesses the thermodynamic efficiency of the process in terms of lost work potential. Technical improvements to the process should show a reduction in lost work and therefore improvement in the efficiency of the process.

The Iogen process is a highly optimised process using state-of-the-art technology for pretreatment and enzyme production. The base case design would use 1000 tonnes per day of aspen wood and would produce about 91 million litres of ethanol per year. Assuming no value for co-products, the break-even selling price for ethanol would be between 45 and 70 cents per litre, depending on the financing method employed, i.e. the assumed capital recovery factor. If co-product credit is added for lignin and molasses, the required ethanol selling price would drop to between 30 and 50 cents per litre.

Forecasts for future technology improvements show that the economic feasibility remains heavily dependent on the value of the co-products; however, it is possible to construct scenarios where the ethanol price could be as low as 10 to 20 cents per litre, including co-product credits, and between 20 and 35 cents per litre without the co-product credits.

Potential improvements to the process include the following: reduced enzyme requirements; reduced enzyme production cost; xylose fermentation to ethanol; lower cost feedstock; and substitution of wood sugars for lactose for enzyme growth.

These low values for the required ethanol selling price could be achieved within the next five years if the rate of technology improvement continues at the pace experienced over the past five years, and assumes that C5 fermentation to ethanol is commercially ready in the same time period.

The basic methodology developed to evaluate the Iogen process is of general utility and applicable to any new or emerging technology. The author feels it would be valuable to apply this approach to other processes for energy production from renewable feedstocks, particularly the thermoconversion, liquefaction technologies.

Résumé

Le principal objectif de ce projet était de fournir à Énergie, Mines et Ressources Canada (EMR) une évaluation technique et économique du procédé de bioconversion de bois en éthanol développé par Iogen. La technique d'évaluation consistait notamment à mettre au point un modèle de simulation sur ordinateur du procédé au moyen du chiffrier électronique Lotus 1-2-3. Le modèle fut créé à partir d'une analyse technique complète du procédé, notamment des bilans thermiques et massiques, ainsi que d'une évaluation économique préliminaire.

Le modèle fut utilisé pour soumettre le procédé à des analyses de sensibilité et estimer les paramètres ayant des répercussions économiques notables ainsi que les possibilités d'améliorer dans l'avenir l'aspect économique du procédé. Les paramètres les plus importants servirent ensuite dans des simulations de Monte Calro visant à estimer la possibilité d'apporter des améliorations au procédé dans l'avenir et à évaluer son intérêt commercial. Enfin, le procédé a fait l'objet d'une analyse fondée sur le deuxième principe de la thermodynamique du procédé en terme de possibilité de travail perdu. L'apport d'améliorations techniques au procédé devrait se traduire par une réduction du travail perdu, et de là, par une amélioration de l'efficacité du procédé.

Le procédé d'Iogen, qui a un rendement élevé, utilise une technologie de pointe aux étapes du traitement préalable et de la production d'enzyme. Dans le cas de base, l'utilisation de 1000 tonnes de tremble par jour permettrait de produire environ 91 millions de litres d'éthanol par année. Lorsqu'on suppose que les co-produits n'ont aucune valeur et qu'on utilise le facteur de recouvrement du capital présumé comme méthode de financement, le prix de vente au seuil de rentabilité se situe entre 45 et 70 cents le litre dans le cas de l'éthanol. Lorsqu'on attribue une valeur monétaire à la lignine et à la mélasse en tant que co-produits, le prix auquel l'on peut vendre l'éthanol diminue, variant de 30 à 50 cents le litre.

Selon des prévisions touchant les améliorations de cette technologie dans l'avenir, la rentabilité du procédé demeure très dépendante de la valeur des co-produits; il est toutefois possible de créer des scénarios dans lesquels le prix de l'éthanol pourrait être de 10 à 20 cents le litre lorsque les co-produits ont une valeur monétaire, et de 20 à 35 cents le litre sans co-produits à valeur monétaire.

Parmi les améliorations qui pourraient être apportées au procédé, signalons des besoins en enzyme réduits; un coût de production d'enyzme diminué; la transformation de xylose en éthanol par fermentation; une charge d'alimentation de coût moins élevé; et le remplacement du lactose par des sucres de bois aux fins de la

production d'enzyme.

L'éthanol pourra peut-être se vendre à ces prix peu éleves au cours des cinq prochaines années si l'amélioration technologique se poursuit au rhythme des cinq dernières années et si le procédé de production d'éthanol par fermentation de C5 devient, entretemps, commercialisable.

La méthode de base mise au point pour évaluer le procédé d'Iogen est utilisable à des fins générales et applicable à n'importe quelle technologie nouvelle ou en voie d'élaboration. L'auteur estime qu'il serait intéressant d'appliquer cette façon de faire à d'autres procédés aux fins de la production d'énergie à partir de charges d'alimentation renouvelables, particulièrement les technologies de la conversion thermique et de la liquéfaction.

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Appendix A. Process Description

This section contains a description of the Iogen Enzymatic Hydrolysis reactor process operations, including the following principal functional sections:

Section 100	Feedstock Handling
Section 200	Enzymatic Hydrolysis, including Steam Explosion Pretreatment Enzyme Production, Hydrolysis Reaction
Section 300	Fermentation
Section 400	Ethanol Purification
Section 600	Offsite Tankage
Section 700	Waste Treatment
Section 800	Utilities

The process design has been adapted from previous published work by Badger Engineers, A.D. Little, and Stone and Webster Engineering Corporation. The following reports served as basic source material:

A.D. Little: Technical and Economic Feasibility of Enzyme Hydrolysis For Ethanol Production From Wood June 1985, NYSERDA Report 85-9, SERI Report 625-RIER-BEA-84.

Badger Engineers: Economic Feasibility Study of an Acid Hydrolysis Based Ethanol Plant - December 1984, SERI Subcontract No. ZX-3-03026-2.

Stone and Webster Engineering Corporation: Economic Feasibility Study of an Enzyme-Based Ethanol Plant - April 1987 - Subcontract ZX-3-03097-1, DE87001189.

The Badger design for a 25 million gallon-per-year ethanol plant was modified by removing the acid hydrolysis and furfural recovery sections, and adding equivalent-capacity facilities for stream explosion pretreatment, enzyme production, and enzymatic hydrolysis reaction. The Stone and Webster steam explosion pretreatment design was used with size modification; the A.D. Little design for enzyme production and hydrolysis reaction was modified and sized based on the Iogen process conditions. The ICARUS computer-aided plant costing system was used to determine capital cost for all sections of the plant.

2 Unit Operations

The operating units of the plant are described in detail in the following sections. Figure 1 shows a block flow diagram of the process with the principal input and output streams. The stream letters on the diagram refer to the material balance section of the Lotus 1-2-3 spreadsheet model developed based on this design.

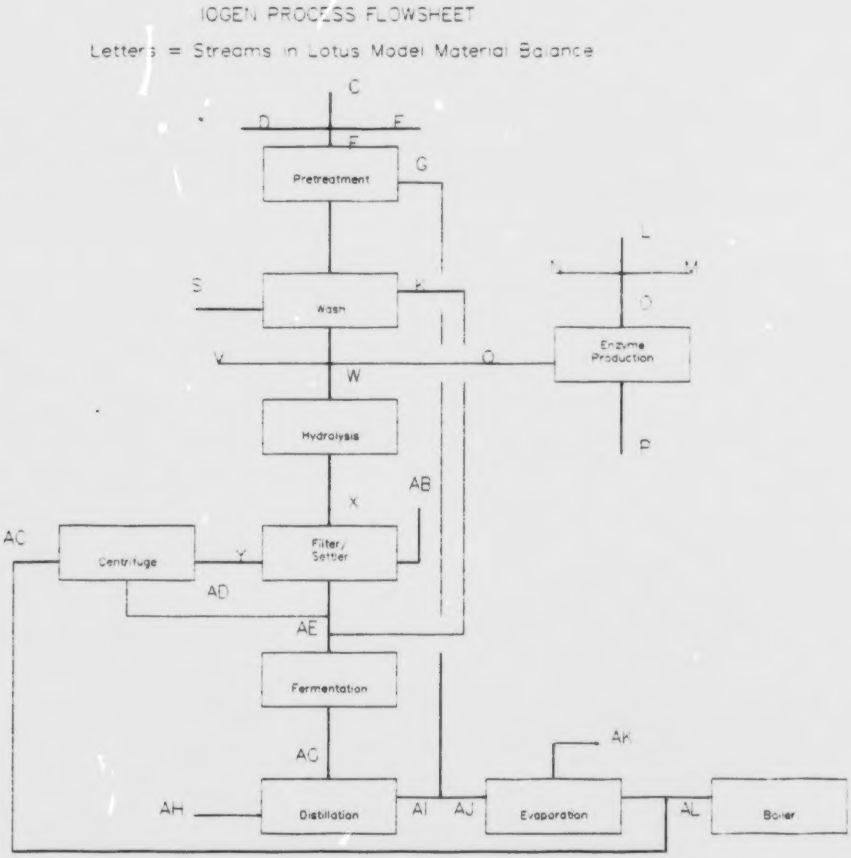
IOGEN PROCESS FLOWSHEET
Letters = Streams in Lotus Model Material Balance
C
D
E
F
Pretreatment
G
S
Wash
K
L
N
M
O
Enzyme Production
V
W
Q
P
Hydrolysis
X
AB
AC
Centrifuge
Y
Filter/ Settler
AD
AE
Fermentation
AG
AK
AH
Distillation
AI
AJ
Evaporation
AL
Boiler

Figure 1. Iogen Process Flow Diagram

2.1 Section 100 Feedstock Handling

Fresh wood chips (40% moisture) are delivered by rail (railcar type 60 short ton net capacity) or truck (truck trailer type 24 short ton net capacity). The receiving station consists of a hydraulic truck dumper, a truck weigh scale, a rail grating, and a railcar weigh scale. Chips are unloaded into the washing flume which allows separation of heavy tramp material such as rocks and large metal items which sink to the bottom of the flume. Chips are swept by the flume pump (PP-101) and discharged to a bucket conveyor GS-101 which transfers the chips to the wood pile. Periodically, the flume is emptied and separated tramp material cleared. Water entrained with the chips as they are conveyed from the flume drains back from the conveyor.

The wood pile holds two weeks, supply of wood chips and is managed on a first-in, first-out basis by means of a front-end loader truck (GM-104A). Chips are fed from the pile through a vibratory chip pile screen (with a 6 inch aperture) using a front end loader (GM-104B) to the belt conveyor (GS-102) which starts below ground. Entrained small metallic items down to one-half inch size are removed by a magnetic separator (GS-105). The belt conveyor transfers the chips to the hydrolysis process (Section 200).

2.2 Section 200-1 Steam Explosion Pretreatment

Wood chips are transported by conveyor from the storage area and loaded into the steam explosion feed bins (M-203A-D) by a vibrating rotary feeder (W-201). The feed bins provide surge capacity for the intermittent loading of the four steam explosion guns (V203A-D). The mechanism of steam explosion is to disrupt the cellulose microfibrils, detach the lignin, increase the surface area of cellulose available for enzymatic attack, and increase the susceptibility of the cellulose to hydrolysis by altering the cellulose crystalline structure. Four explosion guns, each containing 30 cubic feet, are required to process the wood feed. Each steam explosion gun is fired once every 22.5 seconds.

A single steam explosion gun cycle consists of loading the gun with wood chips; raising the gun internal temperature and pressure to 464°F, 470 psig by high pressure (HP) steam injection; cooking the chips for five seconds at temperature; and explosion of the chips into the MP flash vessel (M-201). The explosion consists of forcing the softened chips out of the steam explosion vessels by rapidly reducing the systems pressure. The energy of steam explosion is released as 60 psig steam in the MP flash vessel where the flash steam is recovered for process use. The flash vessel is of sufficient size to dampen the intermittent steam surges from all four guns. The defibrated, exploded pulp is then cooled by vacuum flash in the vacuum flash vessel (M-202). A portion of the beer still (AS-401) (Section 400) bottoms is recycled to the vacuum flash to wash the solids fraction (pulp) from the vessel. The flashed vapors are condensed in a knockback condenser (T-201). A vacuum pump (R-201) is installed to remove noncondensibles from the flash vessel to maintain vacuum conditions.

The cooled pulp is now processed in the countercurrent water/alkali wash (V-201). The countercurrent wash system consists of a traveling belt filter unit. This washer is limited to a 10 weight percent solid feed so that liquid may be properly distributed along the length of the wash unit. To obtain this consistency, the pulp in the vacuum flash vessel (M-202) is diluted with recycle wash waters from the countercurrent wash (V201). The purpose of the countercurrent wash unit is to remove the soluble hemicellulose sugars and extract the lignins with sodium hydroxide. In the first wash stages, the pulp is washed with beer still (AS-401) (Section 400) bottoms product. This stage is followed by a clean wash with process makeup water. The water wash is essential to remove the water-soluble degradation products (phenolics, wood derivatives, etc.), that are inhibitors of yeast fermentation and the activity of the enzyme complex.

2.3 Section 200-2 Enzyme Production

The fed batch enzyme production system is designed such that the solids feed stream is essentially continuous. Seven separate enzyme fermentation tanks are used, with one additional unoperated tank being out of operation as a reserve, for a total of eight. The total batch cycle time for each tank is five days or 124 hours, including emptying and sterilization for the next batch. One batch is started each 18 hours, with filling taking four hours. Fresh solids are added to each tank approximately every 24 hours or four times during the entire batch cycle.

One batch is emptied each 18 hours after 100 hours on stream. Emptying takes four hours and the remaining 10 hours before starting the next batch are used for sterilization and cleaning. Dilution water, nutrients, and cell recycle are added only once for each cycle during the initial filling of the tank. Fresh solids and caustic for neutralization are added twice times during each cycle. The reaction heat is removed from the fermenter vessels by external circulation heat exchangers cooled with chilled water.

Initial lactose concentration in the fermenters is about 1.7 weight percent, and total solids concentration is about 9.4 percent. Cell density is initially maintained at seven grams per liter, and initial corn steep liquor concentration is three weight percent. Final enzyme concentration is 40 IU per milliliter which translates to an enzyme productivity of about 400 I.U.per liter per hour.

A schematic of the enzyme production area is shown in Figure 200-2. Whey permeate concentrate, in which the contained lactose will be the carbon source for enzyme growth, which contains on average 15% to 16% lactose is trucked to the facility from regional cheese plants in refrigerated tank wagons. The permeate is unloaded, heated via direct steam injection, and stored in two 757 cubic meter (200,000 gallon), hot (68°C) storage tanks.

The receiving area is designed to unload a 38 cbic meter (10,000-gallon) truck in less than 30 minutes. The receiving area is operated during the day shift, five days per week (approximately 135,000 gallons per day). The 1,514 cubic meters (400,000 gallons) of storage provided is equivalent to eight days of normal plant operation.

Cheese producers commonly add small amounts of hydrogen peroxide to the whey permeate before transporting it any great distance. The peroxide is expected to decompose during the period of heated storage and will not interfere with the enzyme production fermentation. Permeate is metered from the storage area to a blending surge tank (TK-213) where it is diluted with process water and media salt solutions, adjusting the concentration of lactose to 50 grams per liter. From the blending tank, the solution is metered to a pasteurizer (PKG-218), and then pumped to a pasteurized media surge tank (TK-222).

The formulation of the fermentation media has been adjusted from the traditional basal media reported in the literature. The adjustment is in the amount of phosphate salts that are normally added to supply Tricroderma reesei's phosphorus requirement and to buffer the media. It has been assumed that only 20% of the reported amount of phosphorus is required and that use of pH control through HN_4OH addition will eliminate the need for 80% of the phosphate salts.

From the surge tank, the solution is pumped to one of eight 50,000-gallon continuous fermenters (TK-224 A-H). Seed inoculum for the initial start-up of the fermentation section is supplied through a donor system consisting of three staged fermenters of 50 (TK-236), 1000 (TK-237) and 20,000 (TK-238) liters, respectively. The doner system can supply 5% inoculum to two of the eight main fermenters every 36 hours. Following initial startup, periodic inoculum requirements can be met by transfer of active culture between the production fermenters.

The control of pH and foam is accomplished by addition of HN4OH (or anhydrous ammonia) and corn oil, respectively. The use of corn oil constitutes another departure from reported laboratory and pilot-plant fermentations, which normally involve the use of SAF-100 for foam control. Since SAF-100 costs over $8 per pound and would add about 12 cents to the price per gallon of alcohol, it is assumed here that corn oil could be used. The concentration is doubled compared to normal SAG-100 levels (200 ppm instead of 100 ppm), but the cost is still much lower.

Removal of the heat of fermentation is done in the eight fermenter coolers (E-229 A-H), which are designed to maintain the required 28°C (82°F) fermentation temperature when exchanging with 10°C (50°F) water supplied directly from wells. The sterile air, needed to meet the 21 mole oxygen per liter-hour required for cell respiration (at 12 gram of cells) is supplied through a compressor (CP-244) and filter (F-223).

The fermenters are equipped with a clean-in-place (CIP) system (PKG-229) which delivers caustic cleaning and rinse solutions through internal spray heads. Provisions for steaming the vessels are also incorporated to assist in freeze prevention during cold weather CIP operation.

Exhaust gases from the fermenters are filtered prior to release to the atmosphere. The spent broth or fermenter beer is continuously harvested and sent to a settling tank (TK-234) to remove mycelia. The settled solids are sent to a vacuum filter (VF-235) to be dewatered to 40% solids. The cake is then washed with sterile water to recover enzyme, and the wash waters are sent along with the press liquor and the clarified broth from the settling tank to the broth well (TK-243). The broth well provides for approximately three hours of capacity. Additional short-term surge requirements can be met by adjusting the fermenter residence time without seriously affecting the overall production of enzyme.

2.4 Section 200-3 - Enzyme Hydrolysis System

Exploded wood from Section 200-1 is conveyed (C-250) to one of two ultraviolet-lighted surge bins (H251 A,B) which feed the dual hydrolysis trains. The surge bins are sized for a total of four hours of normal operating capacity and operated with minimal holdup to minimize problems with contamination. All transfer conveyors are covered, also to minimize potential contamination.

The exploded wood is conveyed from the storage bins to a distributing conveyor system (C-253) that feeds the ten 1794 cubic meter (474,000 gallon) hydrolysis tanks (TK-313 A-J). The tanks are initially charged with enzyme broth from Section 200-2; exploded wood is then added in small increments over a 24-hour period.

It is impossible to slurry or mix high (8%) concentrations of exploded wood efficiently until there has been some initial hydrolysis to reduce the average particle size. However, following a few hours of hydrolysis, even fibrous feedstocks will form easily stirred slurries at concentrations exceeding 10% to 12%. The proposed fed-batch operating strategy relies on a significant amount of hydrolysis taking place during the first 24 hours to allow for a substrate concentration of 16.5 (based on total substrate fed) and a maximum concentration of insolubles of 10% (at 24 hours). This method of operation permits production of higher concentrations of sugars than can be achieved in simple batch operation and also greatly reduces the maximum power required for agitation.

The pH of the hydrolysis slurry is continuously monitored and controlled at 4.8 via addition of mineral acid or caustic soda solution. Since the enzyme broth is somewhat buffered and slightly acid there is normally some requirement for base addition. However, no pH change results from the hydrolysis reaction and, therefore, excessive quantities of base addition would occur only if there were microbial contamination.

The temperature of the hydrolysis slurry is also monitored and controlled at 48°C+2°C via direct injection of low pressure steam. This may present a problem with local inactivation of enzyme; however, the hydrolysis vessels are well-insulated and the calculated mixed feedstock and enzyme broth temperature is close to 48oC. Therefore, the steam requirement is small and any enzyme inactivating is hopefully minor. Circulating the mixture through external heat exchangers or using submerged heating coils would reduce the thermal inactivation of enzyme as compared to the present scheme, but these options were rejected because of minimal benefit, greatly increased cost, and problems with vessel cleaning.

The hydrolysis tanks are also sparged with carbon dioxide (CO_2) from Section 300 to insure anaerobic conditions during hydrolysis. The CO_2 is first compressed (CP-255) and then sterilized by filtration (F-256). The sterilized CO2 is then sparged at a rate equivalent to 10% of the head space volume per minute.

Following the 72-hour hydrolysis, the tanks are drained, cleaned-in-place using a dual caustic wash and rinse, and refilled in eight hours. Two hydrolysis tanks are turned around in each eight-hour shift.

The hydrolyzate is then pumped (P-263 A-D) to a solid-bowl centrifuge (CT-264) where it is separated into a 50% solids slurry and a clarified hydrolyzate. The centrafugate is then pumped (P-267 A,B) to Section 400 (alcohol production). The lignin-rich filter cake is conveyed (C-268) to the fluid-bed boilers in Sectioin 800 for use as fuel.

2.5 Section 300 - Fermentation (Batch)

The fermenters are batch operated and consist of eight 250,000 gallon vessels that are arranged in sets of four, with one heat exchanger and circulation pump for each fermenter set. The fermenters are designed for a liquid loading of 80% of maximum capacity. Since cooling is needed for only about eight or ten hours out of the 48-hour fermentation cycle, one exchanger will service the needs of four fermenters. The fermenters are filled on a three-hour cycle.

The yeast, Saccharomyces cervisiae, is manually added to a yeast mix-tank and then transferred to the fermenter as it is being filled (about 300 lb of yeast per batch). The yeast is purchased rather than manufactured on location. The inlet mash temperature is about 80°F, and the temperature gradually rises to a maximum of about 95°F during the peak fermentation period. Cooling is provided during this peak period by recirculation of the mash through the fermenter cooler. Well water at 60°F is the cooling medium. Each fermenter requires a flow of approximately 1,200 gallons per minute during the peak period. The recirculation for cooling also serves to agitate the tank. At the end of the fermentation period, the fermenter contents are transferred to the beer well (TK-400) from which they are pumped continuously to the ethanol purification section, Unit 400.

The fermenters are cleaned and sterilized by means of automatic spraying machines which are installed in each fermenter tank. Each tank has two such spraying machines. After each fermentation cycle, the tank is washed with a cleaning solution; sterilized with an iodine solution; and rinsed with clean, sterile water in preparation for the next cycle.

2.6 Section 400 - Ethanol Purification

Dilute beer containing 3.3 weight percent ethanol from fermentation (Unit 300) is stored in a dilute beer feed tank (MT-406) at 90°F to prevent contamination. From there it is pumped by dilute beer feed pump (PP-409A/S) on flow control to exchange heat with hot steam condensate from the shell side of the column reboilers. The fresh feed, along with recycled bottoms from the rectification column, then enters a degasser drum (MS-401) where some of the dissolved CO_2 leaves as flash vapor. The degasser drum condenser (TT-402) uses cooling water to condense and recover the light organic compounds, in addition, some water from the flash vapor and these liquids return to (MS-401) through a loop seal. The remaining cooled vent vapor passes into the low pressure vent header. The degassed feed then passes through a loop seal and enters beer column (AS-401) on tray 12.

AS-401 is an atmospheric column with 16 sieve trays and is designed to concentrate the ethanol to 40 weight percent in the overhead while losing negligible amounts in the stillage. Heat is supplied to the column by beer column reboilers (TT-403A/B). These are thermosiphon reboilers and the heating medium is low-pressure steam. The process condensate from (TT-403A/B) is further cooled in cooler (TT-412) and feed preheater (TT-413).

The flow of stillage from the bottom of the beer column is controlled by the column liquid level and is pumped by beer column bottoms pump (PP-401A/S) to the field-effect evaporator (GE-701).

Overhead vapor from AS-401 is condensed in beer column condenser (TT-405) using cooling water and collected in beer column reflux drum (MS-402). Vapor from MS-402 is further condensed in beer column vent condenser (TT-406) using cooling water, and the liquid is returned to the drum. The remaining cooled vent passes into the low pressure vent header.

Reflux to AS-401 is pumped by beer column reflux pump (PP-403A/S) on flow control reset by reflux drum level control. Distillate product is fed to tray 14 of rectification column (AS-402) by PP-403A/S on flow control reset by temperature control from a tray near the top of AS-401.

AS-402 is an atmospheric column with 24 sieve trays and is designed to concentrate the ethanol to its azeotropic composition (91.2 weight percent) in the overhead. The bottoms stream, containing 3.5 weight percent ethanol in water, is pumped by rectification column bottoms pump PP-407A/S on level control and recycled as feed to the beer column through MS-401. Heat is supplied to this column by rectification column reboiler (TT-409). This is a thermosiphon reboiler, and heating medium is 50 psig steam controlled by the column bottoms pressure.

Overhead vapor from AS-402 is condensed in rectification column condenser (TT-410) using cooling water and collected in rectification column reflux drum (MS-405). Vapor from MS-405 is further condensed in the rectification column vent condenser (TT-411) using cooling water, and the liquid is returned to the drum. The remaining cooled vent vapor passes into the low pressure vent header.

Reflux to AS-402 is pumped by rectification column reflux pump (PP-408A/S) on flow control reset by reflux drum level control. Distillate product is pumped to molecular sieve feed tank (MT-404) by PP-408A/S on flow control reset by temperature control from a tray near the top of AS-402.

Several components (chiefly amyl, isoamyl, and propyl alcohols, termed fusel oils) tend to accumulate within the rectification column and would eventually affect the column's performance if not removed. A small, continuous liquid sidedraw purge removes these components by gravity flow. The sidedraw stream is mixed with process water, cooled in fusel oil cooler (TT-407) by cooling water, and enters fusel oil decanter (MS-403). There the oily phase is decanted and pumped by fusel oil pump (PP-405A/S) on level control to fusel oil storage tank (MT-605). Water and dissolved alcohols are returned at AS-402 on flow control by wash return pump (PP-404A/S).

Azeotropic ethanol is pumped from MT-404 by molecular sieve feed pump (PP-406A/S) on flow control to molecular sieve drying unit (GZ-401). This package unit, consisting of three towers and a regeneration skid, will dehydrate the ethanol to 199+ proof via adsorption into the desiccant. The desiccant (molecular sieves) preferentially absorbs water over ethanol as the ethanol passes through the desiccant bed. The spent (saturated) desiccant is regenerated by simultaneously applying heat via embedded steam tubes and pulling a vacuum on the bed using a condenser and a vacuum pump. Dehydrated ethanol product is denatured and sent to ethanol product tanks (MT-601A/B). Waste water is sent to equalization tank (MT-703).

2.7 Section 600 - Offsite Tankage

Offsite tankage is provided for bulk storage of intermediate and final liquid products, sulfuric acid, gasoline and diesel fuel, and fire water.

Ethanol product from molecular sieve package unit (GZ-401) is pumped to ethanol product tanks (MT-601A/B). Prior to entering the tank, the ethanol is denatured by blending with gasoline in the proportion five gallons of gasoline per one hundred gallons of ethanol product. Gasoline delivered by truck or railcar is stored in gasoline storage tank MT-610 which has two days capacity. The gasoline is blended into the ethanol by gasoline blending pump (PP-610A/S) on flow control. Denatured ethanol is transported to the shipping point by ethanol export pumps (PP-601 A/B/S).

Fusel oil product is pumped by fusel oil pump (PP-405A/S) to fusel oil storage tank (MT-605). Fusel oil is transported to the shipping point by fusel oil export pump (PP-605A/S).

Hydrolyzate from Section 200 is pumped to fermentation feed tank (MT-604) at 122°C, a temperature selected to inhibit contamination by unwanted microbial growth. Air vent filter (GF-604) mounted on the vent of MT-604 also prevents contamination from the atmosphere. Hydrolyzate is transported to fermenters (MR-402A/B/C/D and MR-303A/B/C/D) by the fermentation feed pump (PP-604A/S) via fermentation feed cooler (TT-604) which cools the hydrolyzate to 84°F using cooling water.

Diesel fuel delivered by truck is stored in diesel fuel tank MT-609 which has a one-month capacity. Fuel is delivered to mobile equipment by diesel fuel pump (PP-609A/S).

Fire water tank (MT-607) and fire water pump (PP-607A/S) are remotely located from the process units and offsite tankage.

2.8 Section 700 - Waste Treatment

The environmental unit consists of three parts: an evaporation section, an anaerobic digestion and aerobic treatment section, and a low pressure vent system.

In the evaporation section, a three-stage evaporator is used to produce mixed solvents at 60% concentration in water to be burned as liquid fuels to produce steam. About one-half of the recovered condensate is recycled to the process and about one-half is sent to anaerobic digestion.

Beer column bottoms pump (PP-401A/S) transports stillage to the first effect evaporator (GE-701) running at 14 pounds per square inch-gage (psig). Heat for the first effect is provided by first effect heater (TT-701) using 50 psig steam. Vapors from the first effect are condensed in second effect heater (TT-702) which provides heat for second effect evaporator (GE-702) running at 11 psia. Liquid is pumped from the first effect to the second effect on level control by first effect pump (PP-701A/S). Similarly, second effect pump (PP-702A/S) feeds third effect evaporator (GE-703) on level control and vapors from the second effect condense and provide heat for the third effect in third effect heater (TT-703). Vapors from the third effect are condensed in evaporator condenser (TT-704) using cooling water.

The pressure in the third effect is controlled at three psia by evaporator vacuum system (PE-704) using 50 psig steam as the motive source and a pressure control bypass that allows steam back to the inlet to (TT-704).

Liquid from the third effect, containing a mixture of about 60% organics and 40% water, is pumped on level control to rotary filter (GF-704) where precipitated salts are separated and sent to disposal. Solid-free liquid is then sent to mixed solvent tank (MT-702) for storage.

Boiler feedwater demineralizer regeneration effluent from GU-803A/B and boiler water blowdown from MS-802 are also treated by evaporation. Condensate from the evaporators is collected in Hotwell Decanter (MS-701) where liquid phase separation can occur. The organic overflows a baffle and is pumped on level control by solvent pump (PP-706A/S) to solvent cooler (TP-706), cooled by cooling water, and sent to MT-702. Waste water is pumped on interface level control by evaporator waste water pump (PP-705A/S) to stillage cooler (TT-705), cooled by cooling water. The temperature is controlled using a bypass line around TT-705. About one-half of the waste water is recycled to the process and the remaining waste water is sent to anaerobic treatment.

MT-702 contains mixed solvents collected from MS-701 and GF-704. Solvent is transported by mixed solvent pump (PP-707A/S) to boilers (HB-801A/B) where the solvent is burned to produce high pressure steam.

In the anaerobic treatment section, the Celrobic process is used. Waste water (evaporator condensate from TT-705, flume washings from PP-101, and molecular sieve runoff from GZ-401) is collected in equalization tank (MT-703) and kept blended by equalization tank educators (PE-711). Reactor feed pumps (PP-708A/S) pump waste water on flow control to reactor feed heater (GU-705) which directly injects low pressure steam on temperature control. After mixing with recycled reactor effluent, the waste water is fed to anaerobic reactor (MT-704). Ninety percent of the process effluent COD is removed in this high rate anaerobic digester. The digester produces methane gas which passes through off-gas suction knock-out pot (MS-706) to off-gas blower (PB-710). Off-gas is compressed and sent to off-gas knock-out drum (MS-709). A split range pressure controller maintains the reactor outlet pressure by recycling compressed off-gas via off-gas cooler (TT-701), cooled by cooling water, or making up with nitrogen. Excess system pressure will open a back pressure control valve allowing off-gas into off-gas burner (GQ-706) where it is flared.

Liquid effluent from MT-704 overflows into reactor surge drum (MS-705) and is pumped on level control by reactor recycle pump (PP-709) to biotreater (MT-707). A portion is recycled to the reactor inlet.

The remaining COD is removed in the aerobic treatment section. Effluent from anaerobic treatment is combined with recycled underflow from the secondary clarifier and filtrate from the filtrate sump and fed to biotreater (MT-707). The biotreater is aerated by aeration blowers (PB-712B/S). Effluent from the biotreater is combined with sand filter backwash and enters secondary clarifier (GV-708). Overflow from the clarifier is used as cooling tower makeup and is pumped on level control by final effluent pumps (PP-717A/S).

A portion of the clarifier underflow is recycled on flow control as feed to the biotreater and the remainder is pumped on flow control by sludge pumps (PD-713A/S) to filter feed tank (MS-708). Filter feed pump (PD-714A/S) mixes sludge with polymer mixer (GA-711) and the belt filter press separates solids for disposal. Filtrate is collected in filtrate sump (MF-709) and recycled to the biotreater by filtrate sump pump (PP-715).

Low pressure vents from all units are drawn into low pressure vent knock-out drum (MS-710) to remove entrained liquids and transported by low pressure vent blower (PB-717A/S) to the firebox of boilers (HB-801A/B) where they are mixed with combustion air. The suction pressure of (PB-717A/S) is controlled using a pressure control bypass line.

Low Pressure Vents

Most of the low pressure vents contain air or carbon dioxide saturated with water and small amounts of volatile organics. The air comes both from displacement during filling of vessels and from release of air trapped in pores in the wood. The organics are mostly ethanol and the extraneous material from wood such as terpenes and extractive resins. These would present odor problems if vented directly to the atmosphere. Scrubbing with water would be inadequate since alpha pinene and oleic acid are insoluble. Recovering such small amounts of organics by chilling and condensing is uneconomical. Therefore, a system is provided to incinerate the vents by mixing them with combustion air in the boilers.

2.9 Section 800 - Utilities

The utilities unit consists of the boilers and steam distribution system, the boiler feedwater system, the turbogenerator system, the cooling water system, the process water system, and the plant and instrument air systems.

Boilers and Steam Distribution System

The boilers (HB-801A/B) are designed to burn solid, liquid, and gaseous fuel byproducts from the process units in order to generate 1100 psia steam for use in electrical power generation. Solid fuels comprise about 53% of total byproduct fuel heating value. Liquid fuel, comprising about 46% of total fuel heating value, is a mixture of solvents, sugar, acids, dissolved organic salts, and soluble tars in a 36% water mixture. Fuel gas comes from anaerobic digestion and comprises less than 1% of total heating value.

Gas and liquid fuels are burned directly but lignin is fed to a Flakt type drying system which dries and fluidizes the solids into the burners using boiler flue gas. No other solid fuel (such as coal) will be utilized as there is always an excess of byproduct fuel available over normal process unit energy requirements. Diesel fuel is used for startup.

Low pressure vents are collected, compressed, and injected into the boilers to mix with combustion air prior to burning. None of these vents contain an explosive mixture either singly or in combinations. They contain mostly air or carbon dioxide saturated with water and with very small amounts of organics.

Users of 150 and 50 psig steam are supplied with steam letdown from 1100 psia through a turbogenerator. All recoverable condensate is returned to the boiler feedwater system.

Boiler Feedwater System (details not shown on PFD)

Boiler feedwater preparation consists of makeup process water demineralization, condensate polishing, deaeration, and chemical dosing.

Recoverable condensate is collected in condensate collection system (GU-805) (package unit). Flashed low pressure steam is used in the deaerator. Condensate is then pumped through condensate polisher (GU-804A/S) to condensate surge drum (MS-804). Makeup process water is introduced on level control via demineralizers (GU-803A/B), a package unit consisting of anion and cation resin beds with intermediate degasifier and regeneration equipment. Deaerator (GV-806) is fed by deaerator feed pump (PP-809A/S) on flow control reset by level control. The deaerator runs at 10 psig and expels air and steam to the atmosphere. Steam to the deaerator is fed on flow control and is supplied by flashes from recovered condensate and from boiler blowdown flash drum (MS-0802) and made up from the 50 psig steam header. Boiler blowdown is sent to evaporator (GE-701) by blowdown pump (PP-806A/S).

Demineralizer regenerant effluent is sent to evaporator (GE-701). Deaerated boiler feedwater is dosed with hydrazine and ammonia made up in hydrazine addition unit (GU-807) and ammonia unit (GU-808). BFW pump (PP-808A/S) feeds boilers (HB-801A/B). The boiler steam drums are dosed with phosphate made up in phosphate addition unit (GU-809). A shed enclosed the three chemical additions units. Hydrazine is transferred from hydrazine drum (MS-803) by hydrazine transfer pump (PP-807) to be mixed with condensate in GU-807. Liquid ammonia from rented tanks is mixed with condensate in GU-808. Phosphate dumped from bags is mixed with condensate in GU-809. BFW chemicals are introduced into the boiler system by variable flow metering pumps.

Turbogenerator (details not shown on PFD)

Turbogenerator package unit (GZ-811) is rated to take 1100 psia, 825°F steam and generate 45 mw of electricity. The unit includes a condenser, vacuum ejector set, and controls. Four percent of the steam is let down in a topping cycle to 150 psig; 66% is let down to 50 psig; and the remainder is condensed at 89 mm Hg(A). Turbine condensate pump (PP0719A/S) returns condensate to the boiler feedwater system.

Cooling Water System

Cooling tower (GT-812) provides cooling water at 88oF. Cooling water distribution is maintained at a pressure of 60 psig by cooling water pumps (PP0812A-H). Cooling tower blowdown containing dissolved salts at 200 ppm is discharged directly to the environment. Cooling tower blowdown contains zero COD.

Process Water System

Process water preparation consists of filtering well water pumped by well water pumps (PP0813A/B/S) through a sand filter and anthracite bed (GF-801). Process water transfer pump PP-802AS feeds process water tank (MT-801). Backwash feed pumps PP-804A/B provides a daily backwash flow to GF-801. Backwash overflow is collected in backwash transfer tank (MF-805) and is transported by backwash transfer pumps (PP-805A/S) to clarifier (GV-708). Process water is distributed via a process water ring main pressurized to 60 psig by process water circulating pump (PP-803A/S).

Plant and Instrument Air Systems (details not shown on PFD)

Plant and instrument air are provided by air compressor (PC-811) operating on pressure control from plant air receiver (MS-806). Instrument air receiver MS-807 is fed via instrument air dryer (GY-810).

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CP-203 AVS-MEDIUM       MAT  : 5500.
WASH FD PUMP P203B  SPAREMHRS : 66ES
    1700 LBS            LAB  : 978.

CP-204 AVS-MEDIUM       MAT  :  5700.
WASH RECYCLE PUMP   P204MHRS :  62ES
    1400 LBS            LAB  : 919.

CP-204 AVS-MEDIUM       MAT  :  5700.
WASH RECYCPMP P204B SPARMHRS : 62ES
    1400 LBS            LAB  : 919.

VP-202 CYLINDER         MAT  : 5400.
VACUMPMP R201A-B (2)ITEMHRS  :  23ES
    390 LBS             LAB  :  343.

VT-202 CYLINDER         MAT  : 40000.
VACUUM FLASH TANK   M-20MHRS : 25ES
    14300 LBS           LAB  : 369.

CT-201 SCROLL-CON       MAT  : 715800.
CONT CENTRIFUGS (3) ITEMHRS  : 1475ES
    9 LBS               LAB  : 21762.

FE-201 VIBRATING        MAT  : 11200.
 IB FDTS W201A-B (2)ITEMHRS  :  21ES
    1300 LBS            LAB  : 351.

CO-202 SCREW            MAT  : 26500.
WASHER SCNCNVYR W-20   MHRS  :  25ES
    4100 LBS            LAB  : 369.

CO-203 CLOSED-BLT       MAT  : 106200.
WSHD CELLCNVYR W203 I=20MHRS : 432ES
    14200 LBS           LAB  : 6375.

VT-201 CYLINDER         MAT  : 177600.
FLSH TKS M201A-B (2)ITEMHRS  :  200ES
    34400 LBS           LAB  : 2475.

VT-203 PLAST TANK       MAT  : 39200.
FED BINS M203A-H (8)ITEMHRS  :  200ES
    650 LBS             LAB  : 2950.

HE-201 FIXED-T-S        MAT  : 124700.
VAC FLASH CONDENSER T20MHRS  : 38ES
    20800 LBS           LAB  : 611.

VT-203 CYLINDER         MAT  : 1025792.
EXP GNS C+150000 (8) ITEMHRS : 200ES
    5800 LBS            LAB  : 2950.
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                    01 ENZYME PRODUCTION SYSTEM - ON GRADE
                       E Q U I P M E N T   L I S T

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                                                                                                 PURCHASED
ORIGIN  EQUIPMENT          I T E M           - - - - - -  D E S I G N   D A T A - - - - - - - - - - - - -EQUIPMENT
        ITEM TYPE     D E S C R I P T I O N                                                      COST
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AT-224  REACTOR    ENZ PROD RCTRD (8)  ITEM   SHELL MAT'L  304SSCIAD        - VOLUME        50000.0  GALLONS 6309600
        W/INTEGRAL AGITATAR                   DIAMETER     14.00    FEET    - HEIGHT           41.00 FEET
        EACH VESSEL - 266,000                 DRIVER SPEED  235.00  RPM     - DRIVER POWER  750.00   HP
        EACH AGITATAR-522,700                 DESIGN TEMP.  350.00  DEG F   - DESIGN PRESS   50.00   PSIG
                      -------                 THICKNESS       0.56  INCHES  - REYNOLDS NO.  5203730
                      788.700                 FLUID DEPTH    59.00  FEET    - TOTAL WEIGHT  146700   LBS
                                              INCLUDES FIELD FAB. BY VENDOR

HT-226  PORIZ-CRUM NH3 STRG TANK TK-226       SHELL MAT'L  CS        LBS    - CAPACITY      16500.00 GALLONS    20700
                                              DIAMETER        8.50  FEET    - LENGTH           49.00 FEET
                                              DESIGN PRESS   15.00  PSIG    - DESIGN TEMP.  650.00   DEG F
                                              THICKNESS       0.31  INCHES  - TOTAL WEIGHT     18200 LBS

'P-240  AVS-MEDIUM NH3 MTRG PUMP P240         MATERIAL      CS              - CAPACITY          5.00 GPM       2600
                                              HEAD           57.00  FEET    - TEMPERATURE    120.00  DEG.F
                                              DRIVER POWER    2.00  HP      - SPEED         1800.00  RPM
                                              TOTAL WEIGHT  600     LBS     - INCLUDES MOTOR DRIVER

VT-227  CYLINDER   NUTRIENT STRG TNK TK 227   SHELL MAT'L  CS        LBS    - CAPACITY      19800.00 GALLONS    44900
                                              DIAMETER       15.00  FEET    - HEIGHT           15.00 FEET
                                              DESIGN PRESS   15.00  PSIG    - DESIGN TEMP.  650.00   DEG F
                                              THICKNESS       0.31  INCHES  - TOTAL WEIGHT  24400    LBS
                                              INCLUDES FIELD FAB. BY VENDOR

CP-241  AVS-PECIUM NUTRIENT PMP P241A         MATERIAL      CS              - CAPACITY        15.00  GPM        2600
                                              HEAD           75.00  FEET    - TEMPERATURE    120.00  DEG F
                                              DRIVER POWER    2.00  HP      - SPEED         1800.00  RPM
                                              TOTAL WEIGHT  600     LBS     - INCLUDES MOTOR DRIVER

CP-241  AVS-PEDIUM NUTRIENT PMP P241 SPARE    MATERIAL      CS              - CAPACITY        15.00  GPM        2600
                                              HEAD           75.00  FEET    - TEMPERATURE    120.00  DEG F
                                              DRIVER POWER  2.00    HP      - SPEED            1800  RPM
                                              TOTAL WEIGHT  600     LBS     - INCLUDES MOTOR DRIVER

VT-215  PLAST TANK MIX TANK TK-215            MATERIAL      FRP             - CAPACITY      25000.00 GALLONS    25000
                                              DIAMETER       12.00  FEET    - HEIGHT           30.00 FEET
                                              TEMPERATURE     660   LBS     - INCLUDES MOTOR DRIVER

CP-217  AVS-PECIUM METERING PMP P217B  SPARE  MATERIAL      316SF           - CAPACITY       120.00  GPM       2700
                                              HEAD           75.00  FEET    - TEMPERATURE    120.00  DEG F
                                              DRIVER POWER  5.00    HP      - SPEED         1800.00  RPM
                                              TOTAL WEIGHT  660     LBS     - INCLUDES MOTOR DRIVER
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VT-222   CYLINDER   SURGE TANK TK-222             SHELL MAT'L   304L             - CAPACITY      25000.00 GALLONS  61700
                                                  DIAMETER      14.00   FEET     - HEIGHT           21.70 FEET
                                                  DESIGN PRESS  15.00   PSIG     - DESIGN TEMP.    650.00 DEG F
                                                  THICKNESS      0.19   INCHES   - TOTAL WEIGHT    19700  LBS

CP-223   AVS-MEDIUM NUTRNT FD PMP P223B    SPARE  MATERIAL      304SF            - CAPACITY        120.00 GPM         2600
                                                  HEAD          75.00   FEET     - TEMPERATURE     120.00 DEG F
                                                  DRIVER POWER   5.00   HP       - SPEED          1800.00 RPM
                                                  TOTAL WEIGHT  660     LBS      - INCLUDES MOTOR DRIVER

CP-223   AVS-MEDIUM NUTRNT FD PMP P223 B SPARE    MATERIAL      304SF            - CAPACITY        120.00 GPM         2600
                                                  HEAD          75.00   FEET     - TEMPERATURE     120.00 DEG F
                                                  DRIVER POWER   5.00   HP       - SPEED          1800.00 RPM
                                                  TOTAL WEIGHT  660     LBS      - INCLUDES MOTOR DRIVER




HE-218   FIXEC-T-S  PASTEURZER PKG218  C=75000    TUBE MAT'L    A 214            - TRANSF. AREA   1000.00 SF          64112
                                                  SHELL MAT'L   A285C            - TEMP TYPE      BEM
                                                  SHELL PRESS.  150.00  PSIG     - SHELL TEMP.     650.00 DEG F
                                                  SHELL DIA.     20.00  INCHES   - SHELL LENGTH     20.00 FEET
                                                  TUBE PRESS.   150.00  PSIG     - TUBE TEMP.      650.00 DEG F
                                                  TUBE DIA.       1.00  INCHES   - TUBE LENGTH      20.00 FEET
                                                  TOTAL WEIGHT  6200    LBS

AT-236   MIXER      1STST SDTNK TK236  C=60000    SHELL MAT'L    316L            - VOLUME           15.00 GALLONS  51290
                                                  DIAMETER       1.33   FEET     - HEIGHT            2.00 FEET
                                                  DRIVER SPEED  2966.00 RPM      - DRIVER POWER      1.00 HP
                                                  DESIGN TEMP.   250.00 DEG F    - DESIGN PRESS     15.00 PSIG
                                                  THICKNESS        0.25 INCHES   - REYNOLDS NO.    402983
                                                  FLUID DEPTH      1.13 FEET     - TOTAL WEIGHT     780   LBS

AT-237   MIXER      2NDST SDTNK TK237 C=240000    SHELL MAT'L   316L             - VOLUME          275.00 GALLONS  23500
                                                  DIAMETER        3.50  FEET     - HEIGHT            4.00 FEET
                                                  DRIVER SPEED 1133.00  RPM      - DRIVER POWER      5.00 HP
                                                  DESIGN TEMP.  250.00  DEG F    - DESIGN PRESS     15.00 PSIG
                                                  THICKNESS       0.25  INCHES   - REYNOLDS NO.   1060730
                                                  FLUID DEPTH     2.98  FEET     - TOTAL WEIGHT      2300 LBS

AT-238   MIXER      3RDST SDTNK TK238 C=760000    SHELL MAT'L   316L             - VOLUME         6000.00 GALLONS  68800
                                                  DIAMETER        9.50  FEET     - HEIGHT           13.00 FEET
                                                  DRIVER SPEED   59.00  RPM      - DRIVER POWER     20.00 HP
                                                  DESIGN TEMP.  250.00  DEG F    - DESIGN PRESS     15.00 PSIG
                                                  THICKNESS       0.25  INCHES   - REYNOLDS NO.    900763
                                                  FLUID DEPTH    11.51  FEET     - TOTAL WEIGHT    10600  LBS

CP-230   AVS-PECIUM RECYCLE PUMPS (8)   ITEM      MATERIAL      304L             - CAPACITY        500.00 GPM         49600
                                                  HEAD          100.00  FEET     - TEMPERATURE     120.00 DEG F
                                                  DRIVER POWER   20.00  HP       - SPEED          1800.00 RPM
                                                  TOTAL WEIGHT      1000 LBS     - INCLUDES MOTOR DRIVER
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HE-229   FIXEC-T-S  FERMENTER CLRS (8)  ITEM   TUBE MAT'L    304S            - TRANSF. AREA 672.0              270400
                                               SHELL MAT'L   A285C           - TEMA TYPE    BEM
                                               SHELL PRESS.  150.00  PSIG    - SHELL TEMP.  650.00   DEG F
                                               SHELL DIA.     10.00  INCHES  - SHELL LENGTH  20.00   FEET
                                               TUBE PRESS.   150.00  PSIG    - TUBE TEMP.   650.00   DEG F
                                               TUBE DIA.       1.00  INCHES  - TUBE LENGTH   20.00   FEET
                                               TOTAL WEIGHT  2000    LBS




GC-244   CENTRIF-M  AIRCMPRSR CP-244 (1)  ITEM MATERIAL      CS              - CAPACITY        6000 CFM
                                               DISCH. PRESS  20.00   PSIG    - DRIVER POWER  800.00 HP
                                               DRIVER SPEED  3986.00 RPM     - INLET TEMP.    68.00 DEG F
                                               NO. STAGES          5         - TOTAL WEIGHT 131400  LBS
                                               INCLUDES MOTOR DRIVER

HE-244A  FIXEC-T-S  INTRCLRS T244A (1)  ITEM   TUBE MAT'L    A 214           - TRANSF. AREA 1000.00 SF        56400
                                               SHELL MAT'L   A285C           - TEMA TYPE    BEM
                                               SHELL PRESS.  150.00  PSIG    - SHELL TEMP.   650.00 DEG F
                                               SHELL DIA.     20.00  INCHES  - SHELL LENGTH   20.00 FEET
                                               TUBE PRESS.   150.00  PSIG    - TUBE TEMP.    650.00 DEG F
                                               TUBE DIA.       1.00  INCHES  - TUBE LENGTH    20.00 FEET
                                               TOTAL WEIGHT  6200    LBS

CP-239   AVS-FIGH   CHLDWTR CIRCPMP (2) ITEM   MATERIAL      CS              - CAPACITY     2000.00 GPM       26800
                                               HEAD          200.00  FEET    - TEMPERATURE   120.00 DEG F
                                               DRIVER POWER  125.00  HP      - SPEED        3600.00 RPM
                                               TOTAL WEIGHT  2900    LBS     - INCLUDES MOTOR DRIVER

CP-239A  AVS-FIGH   CHLDWTR CIRCPMP  SPARE     MATERIAL      CS              - CAPACITY     2000.00 GPM        13400
                                               HEAD          200.00  FEET    - TEMPERATURE   120.00 DEG F
                                               DRIVER POWER  125.00  HP      - SPEED        3600.00 RPM
                                               TOTAL WEIGHT     2900 LBS     - INCLUDES MOTOR DRIVER
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                  04 HYDROLYSIS REACTION SYSTEM - ON GRADE
                     E Q U I P M E N T   L I S T

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                                                                                                     PURCHASED
                                           - - - - - -  D E S I G N   D A T A - - - - - - - - - - - - -EQUIPMENT
ORIGIN   EQUIPMENT        I T E M                                                                    COST
         ITEM TYPE    D E S C R I P T I O N
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VT-258   CYLINDER   HYDRLYSIS RCTRS (10) ITEM   SHELL MAT'L  EPLCS             - CAPACITY     474000.0 GALLONS 7,349,000
                                                DIAMETER      30.00   FEET    - HEIGHT          90.00  FEET
                                                DESIGN PRESS 50.00    PSIG    - DESIGN TEMP.  350.00   DEG F
                                                THICKNESS     0.94    INCHES - TOTAL WEIGHT 522300     LBS
                                                INCLUDES FIELD FAB. BY VENDOR

VT-251   CONE BTM   SRGE BINS H251AB (2)  ITEM  SHELL MAT'L  CS                - CAPACTIY     105000.0 GALLONS   150400
                                                DIAMETER      20.00   FEET    - HEIGHT          45.00  FEET
                                                DESIGN PRESS  0.050   PSIG    - DESIGN TEMP.   68.00   DEG F
                                                THICKNESS      0.25   INCHES - TOTAL WEIGHT 67500      LBS
                                                INCLUDES FIELD FAB. BY VENDOR

CC-253   CLOSED-BLT FEED CONVEYORS (1)  ITEM    MATERIAL      CS               - CAPACITY        60.00  TPH      18,400
                                                LENGTH        100.00  FEET    - WIDTH           18.00  INCHES
                                                DRIVER SPEED 1750.00  RPM     - DRIVER POWER     3.00  HP
                                                SPEED         300.00  RPM     - NO. SECTIONS        1  V
                                                TOTAL WEIGHT 8200     LBS

CC-253   SCREW    FEED CONVEYORS (10)  ITEM     MATERIAL      CS               - RATE            54.00  TPH      46,000
                                                LENGTH         30.00  FEET    - DIAMETER         8.00  INCHES
                                                PROD DENSITY   50.00  PCF     - DRIVER POWER     7.50  HP
                                                TOTAL WEIGHT  1500    LBS

MCT-258  ENCLOSED   AGITRS C=57000 (10) ITEM    SPEED         1800.00  RPM    - DRIVER POWER   250.00 HP        952,000
                                                TOTAL WEIGHT   1300    LBS

HE-272   FIXEC-T-S REACTOR COOLERS (10) ITEM    TUBE MAT'L     304S            - TRANSF. AREA  160.00  SF      272,000
                                                SHELL MAT'L  A285C             - TEMA TYPE     BEM
                                                SHELL PRESS.  150.00  PSIG    - SHELL TEMP.   850.00  DEG F
                                                SHELL DIA.     18.00  INCHES - SHELL LENGTH   20.00  FEET
                                                TUBE PRESS.   150.00  PSIG    - TUBE TEMP.    650.00  DEG F
                                                TUBE DIA.       1.00  INCHES - TUBE LENGTH    20.00  FEET
                                                TOTAL WEIGHT  4900    LBS

CP-271   AVS-PEDIUM RCTYR CIRC PUMPS (10) ITEM  MATERIAL      CS               - CAPACITY     1000.00  GPM      57,000
                                                HEAD          100.00  FEET    - TEMPERATURE   120.00  DEG F
                                                DRIVER POWER  40.00   HP      - SPEED        1800.00  RPM
                                                TOTAL WEIGHT 1400     LBS     - INCLUDES MOTOR DRIVER

CP-271   AVS-MEDIUM RCTRCRCPMP SPAR (10) ITEM   MATERIAL      CS               - CAPACITY     1000.00  GPM      57,000
                                                HEAD          100.00  FEET    - TEMPERATURE   120.00  DEG F
                                                DRIVER POWER   40.00  HP      - SPEED        1800.00  RPM
                                                TOTAL WEIGHT 1400     LBS     - INCLUDER MOTOR DRIVER
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                                                 TOTAL WEIGHT 1000     LBS    - INCLUDES MOTOR DRIVER


CP-267   AVS-MEDIUM HYD PUMP P267A               MATERIAL      CS               - CAPACITY      400.00   GPM        4200
                                                 HEAD          125.00   FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER   20.00   HP      - SPEED        1800.00   RPM
                                                 TOTAL WEIGHT 1000      LBS     - INCLUDES MOTOR DRIVER

CO-268   CLOSED-BLT LIGNIN CONVEYOR C268         MATERIAL      CS               - CAPACITY       60.00   TPH       31600
                                                 LENGTH         125.00  FEET    - WIDTH           18.00  INCHES
                                                 DRIVER SPEED 1750.00   RPM     - DRIVER POWER     2.00  HP
                                                 SPEED         3000.00  RPM     - NO. SECTIONS        1
                                                 TOTAL WEIGHT  6400     LBS

VT-259   PLAST TANK ACID TANK TK259              MATERIAL      FRP              - CAPACITY     5000.00   GALLONS   7000
                                                 DIAMETER        8.00   FEET    - HEIGHT          13.00  FEET
                                                 TEMPERATURE    68.00   DEG F   - TOTAL WEIGHT  930      LBS

CP-261   AVS-MEDIUM ACID TRANS PMP P261A         MATERIAL      216SF            - CAPACITY      100.00   GPM       2900
                                                 HEAD          100.00   FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER    5.00   HP      - SPEED        1800.00   RPM
                                                 TOTAL WEIGHT  700      LBS     - INCLUDES MOTOR DRIVER

CP-261   AVS-MEDIUM ACID TRNS PMP P261B SPARE    MATERIAL       216SF           - CAPACITY      100.00   GPM       2900
                                                 HEAD           100.00  FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER    5.00   HP      - SPEED        1800.00   RPM
                                                 TOTAL WEIGHT  700      LBS     - INCLUDES MOTOR DRIVER

VT-260   PLAST TANK CAUSTIC TANK TK260           MATERIAL      FRP              - CAPACITY     5000.00   GALLONS   7000
                                                 DIAMETER        8.00   FEET    - HEIGHT          13.00  FEET
                                                 TEMPERATURE    68.00   DEG F   - TOTAL WEIGHT  390      LBS

CP-262   AVS-MEDIUM CAUST TRANS PMP P262A        MATERIAL      CS               - CAPACITY      100.000  GPM       3000
                                                 HEAD           100.00  FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER     5.00  HP      - SPEED        1800.00   RPM
                                                 TOTAL WEIGHT  700      LBS     - INCLUDES MOTOR DRIVER

CP-262   AVS-MEDIUM CAUSTRANS PMP P262B SPARE    MATERIAL      CS               - CAPACITY      100.00   GPM       3000
                                                 HEAD           100.00  FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER     5.00  HP      - SPEED        1800.00   RPM
                                                 TOTAL WEIGHT   700     LBS     - INCLUDES MOTOR DRIVER

CP-263   AVS-FIGH   HYD TRANS PUMP (1)  ITEM     MATERIAL      CS               - CAPACITY     2000.00   GPM      40200
                                                 HEAD          200.00   FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER 125.00    HP      - SPEED        2600.00   RPM
                                                 TOTAL WEIGHT 2900      LBS     - INCLUDES MOTOR DRIVER

CP-263   AVS-FIGH   HYD TRANS PUMP   SPARE       MATERIAL      CS               - CAPACITY     2000.00   GPM      12400
                                                 HEAD           200.00  FEET    - TEMPERATURE   120.00   DEG F
                                                 DRIVER POWER   125.00  HP      - SPEED        3600.00   RPM
                                                 TOTAL WEIGHT  2900     LBS     - INCLUDES MOTOR DRIVER

CP-267   AVS-MEDIUM HYD TRANS PUMP P267A         MATERIAL      CS               - CAPACITY      400.00   GPM       3900
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                                                      HEAD          100.00   FEET   - TEMPERATURE   120.00  DEG F
                                                      DRIVER POWER   15.00   HP     - SPEED        1800.00  RPM
                                                      TOTAL WEIGHT  940      LBS    - INCLUDES MOTOR DRIVER

CP-267   AVS-MEDIUM TRNS PMP P267B SPARE              MATERIAL      CS              - CAPACITY      400.00  GPM        3900
                                                      HEAD          100.00   FEET   - TEMPERATURE   120.00  DEG F
                                                      DRIVER POWER   15.00   HP     - SPEED        1800.00  RPM








                                                      TOTAL WEIGHT  940      LBS    - INCLUDES MOTOR DRIVER

VT-270   PLAST TANK WATER STRG TNK TK270              MATERIAL      FRP             - CAPACITY     1500.00  GALLONS  4000
                                                      DIAMETER        5.00   FEET   - HEIGHT         10.00  FEET
                                                      TEMPERATURE    68.00   DEG F  - TOTAL WEIGHT  530     LBS

HE-266   FIXEC-T-S  PASTEURIZER PK266 C=20000         TUBE MAT'L    A 214           - TRANSF. AREA 1000.00  ST         17097
                                                      SHELL MAT'L   A285C           - TEMA TYPE     BEM
                                                      SHELL PRESS.  150.00   PSIG   - SHELL TEMP.   650.00  DEG F
                                                      SHELL DIA.     20.00   INCHES - SHELL LENGTH   20.00  FEET
                                                      TUBE PRESS.   150.00   PSIG   - TUBE TEMP.    650.00  DEG F
                                                      TUBE DIA.       1.00   INCHES - TUBE LENGTH    20.00  FEET
                                                      TOTAL WEIGHT  6200     LBS
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                         06  FERMENTATION 300 UNIT    -  UN GRADE
                             E Q U I P M E N T    L I S T
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ORIGIN :EQUIPMENT :          I T E M              :---------------------- D E S I G N   D A T A ----------------------: PURCHASED:
       :ITEM TYPE : D E S C R I P T I O N :                                                                           : EQUIPMENT:
                                                                                                                        : COST $   :
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   -304 CONE ROOF  BEER WELL MS-304            MATERIAL          CS              - CAPACITY        225000.0 GALLONS        64700
                                                DIAMETER        33.00 FEET       - HEIGHT             33.00 FEET
                                                DESIGN PRESS    0.050 PSIG       - TEMPERATURE        68.00 DEG F
                                                TOP THICK.       0.19 INCHES     - BOTTOM THICK        0.31 INCHES
                                                TOTAL WEIGHT    63900 LBS        - INCLUDES FIELD FAB. BY VENDOR

HE -301 U-TUBE     HTEXGS TY301AM  (8) ITEM    TUBE MAT'L       304LS            - TRANSF. AREA  1400.00 SF               337600
                                                SHELL MAT'L      A285C            - TEMA TYPE          BEU
                                                SHELL PRESS.   150.00 PSIG       - SHELL TEMP.       650.00 DEG F
                                                SHELL DIA.      23.00 INCHES     - SHELL LENGTH       20.00 FEET
                                                TUBE PRESS.    150.00 PSIG       - TUBE TEMP.        650.00 DEG F
                                                TUBE DIA.        1.00 INCHES     - TUBE LENGTH        40.00 FEET
                                                TOTAL WEIGHT     6400 LBS

VT -302 CONE ROOF  FMTRS MR302AM (8) ITEM      MATERIAL          CS              - CAPACITY        225000.0 GALLONS       517600
                                                DIAMETER        33.00 FEET       - HEIGHT             33.00 FEET
                                                DESIGN PRESS    0.050 PSIG       - TEMPERATURE        68.00 DEG F
                                                TOP THICK.       0.19 INCHES     - BOTTOM THICK        0.31 INCHES
                                                TOTAL WEIGHT    63900 LBS        - INCLUDES FIELD FAB. BY VENDOR

VT -305 CYLINDER   STERILIZATION TNK MS-305    SHELL MAT'L       CS              - CAPACITY        10000.00 GALLONS        19800
                                                DIAMETER        12.00 FEET       - HEIGHT             12.00 FEET
                                                DESIGN PRESS    15.00 PSIG       - DESIGN TEMP.      650.00 DEG F
                                                THICKNESS        0.31 INCHES     - TOTAL WEIGHT       11700 LBS

VT -306 CYLINDER   CLEANING TANK MS-306        SHELL MAT'L       CS              - CAPACITY        10000.00 GALLONS        19800
                                                DIAMETER        12.00 FEET       - HEIGHT             12.00 FEET
                                                DESIGN PRESS    15.00 PSIG       - DESIGN TEMP.      650.00 DEG F
                                                THICKNESS        0.31 INCHES     - TOTAL WEIGHT       11700 LBS

CP -304 AVS-LOW    BEER WELL PMP PP304A        MATERIAL         316SF            - CAPACITY         1500.00 GPM              6300
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    25.00 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT     1600 LBS        - INCLUDES MOTOR DRIVER

CP -304 AVS-LOW    BEERWELLPMP PP304S SPARE    MATERIAL         316SF            - CAPACITY         1500.00 GPM              6300
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    25.00 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT     1600 LBS        - INCLUDES MOTOR DRIVER

(    -301 AVS-MEDIUM HEX PPP PP301AM (8) ITEMS MATERIAL         316SF            - CAPACITY          670.00 GPM             32800
                                                HEAD            80.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    20.00 HP         - SPEED            1800.00 RPM
                                                TOTAL WEIGHT     1000 LBS        - INCLUDES MOTOR DRIVER
CP -301 AVS-MEDIUM PP301AM/S SPARE (8) ITEMS   MATERIAL         316SF            - CAPACITY          670.00 GPM             32800
                                                HEAD            80.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    20.00 HP         - SPEED            1800.00 RPM
                                                TOTAL WEIGHT     1000 LBS        - INCLUDES MOTOR DRIVER

CP -305 AVS-HIGH   DISTFDPUMP PP305A           MATERIAL         316SF            - CAPACITY         1500.00 GPM             25500
                                                HEAD           400.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER   200.06 HP         - SPEED            3600.00 RPM
                                                TOTAL WEIGHT     3500 LBS        - INCLUDES MOTOR DRIVER

CP -305 AVS-HIGH   DISTFDPUMP PP305S SPARE     MATERIAL         316SF            - CAPACITY         1500.00 GPM             25500
                                                HEAD           400.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER   200.00 HP         - SPEED            3600.00 RPM
                                                TOTAL WEIGHT     3500 LBS        - INCLUDES MOTOR DRIVER

CP -306 AVS-HIGH   STERILIZ PMP PP306A         MATERIAL          CS              - CAPACITY          200.00 GPM              2500
                                                HEAD           200.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    15.00 HP         - SPEED            3600.00 RPM
                                                TOTAL WEIGHT      640 LBS        - INCLUDES MOTOR DRIVER

CP -306 AVS-HIGH   STERILIZ PMP PP306S SPARE   MATERIAL          CS              - CAPACITY          200.00 GPM              2500
                                                HEAD           200.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER    15.00 HP         - SPEED            3600.00 RPM
                                                TOTAL WEIGHT      640 LBS        - INCLUDES MOTOR DRIVER

CP -303 AVS-LOW    CLEANNGPMP PP303A           MATERIAL          CS              - CAPACITY          300.00 GPM              3100
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER     7.50 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT      770 LBS        - INCLUDES MOTOR DRIVER

CP -303 AVS-LOW    CLEANNGPMP PP303S SPARE     MATERIAL          CS              - CAPACITY          300.00 GPM              3100
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER     7.50 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT      770 LBS        - INCLUDES MOTOR DRIVER

   -307 AVS-LOW    SCRBRCYCPMP PP307A          MATERIAL          CS              - CAPACITY          150.00 GPM              2500
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER     3.00 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT      600 LBS        - INCLUDES MOTOR DRIVER

CP -307 AVS-LOW    SCRBRCYCPMP PP307S SPARE    MATERIAL          CS              - CAPACITY          150.00 GPM              2500
                                                HEAD            50.00 FEET       - TEMPERATURE       150.00 DEG F
                                                DRIVER POWER     3.00 HP         - SPEED            1200.00 RPM
                                                TOTAL WEIGHT      600 LBS        - INCLUDES MOTOR DRIVER
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                              06  FERMENTATION 300 UNIT     -  GM GRADE
                                  E Q U I P M E N T    L I S T

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:           :             :                             :                                                  : PURCHASED:
    CIN  :EQUIPMENT :           I T E M          :-------------------- D E S I G N   D A T A --------------------: EQUIPMENT:
         :ITEM TYPE :  D E S C R I P T I O N     :                                                  : COST $   :
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CP -303 IN LINE     GY303 C-4000      (17) ITEM MATERIAL          316SF           - CAPACITY          20.00 GPM         58128
                                                HEAD             75.00 FEET      - TEMPERATURE      120.00 DEG F
                                                DRIVER POWER      1.00 HP        - SPEED           1800.00 RPM
                                                TOTAL WEIGHT       300 LBS       - INCLUDES MOTOR DRIVER


                              07  FERMENTATION 300 UNIT     -  STRUCTURE
                                  E Q U I P M E N T    L I S T

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:           :             :                             :                                                  : PURCHASED:
.ORIGIN  :EQUIPMENT :           I T E M          :-------------------- D E S I G N   D A T A --------------------: EQUIPMENT:
:        :ITEM TYPE :  D E S C R I P T I O N     :                                                  : COST $   :
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TW -301 SIEVE TRAY CO2OFFGSCRBR AS-301          SHELL MAT'L      A 515           - NO. OF TRAYS          5              22000
                                                DIAMETER          5.00 FEET      - HEIGHT            25.00 FEET
                                                DESIGN TEMP.    100.00 DEG F     - DESIGN PRESS       1.50 PSIG
                                                TRAY SPACING     24.00 INCHES    - TRAY MAT'L        A285C
                                                THICKNESS         0.31 INCHES    - TOTAL WEIGHT       9300 LBS

CP -302 AVS-MEDIUM C-FEED PP302AB (2) ITEMS     MATERIAL         304SF           - CAPACITY         750.00 GPM          9000
                                                HEAD            100.00 FEET      - TEMPERATURE      150.00 DEG F
                                                DRIVER POWER     25.00 HP        - SPEED           1800.00 RPM
                                                TOTAL WEIGHT      1200 LBS       - INCLUDES MOTOR DRIVER

CP -302 AVS-MEDIUM PP302AB/S (2) ITEMS SPARE MATERIAL            304SF           - CAPACITY         750.00 GPM          9000
                                                HEAD            100.00 FEET      - TEMPERATURE      150.00 DEG F
                                                DRIVER POWER     25.00 HP        - SPEED           1800.00 RPM
                                                TOTAL WEIGHT      1200 LBS       - INCLUDES MOTOR DRIVER

CP -308 AVS-MEDIUM UNDRFLOW PP308AB (2) ITEM MATERIAL            304SF           - CAPACITY          75.00 GPM          5400
                                                HEAD            100.00 FEET      - TEMPERATURE      150.00 DEG F
                                                DRIVER POWER      3.00 HP        - SPEED           1800.00 RPM
                                                TOTAL WEIGHT       660 LBS       - INCLUDES MOTOR DRIVER

   -308 AVS-MEDIUM PP308AB/S (2) ITEM SPARE     MATERIAL         304SF           - CAPACITY          75.00 GPM          5400
                                                HEAD            100.00 FEET      - TEMPERATURE      150.00 DEG F
                                                DRIVER POWER      3.00 HP        - SPEED           1800.00 RPM
                                                TOTAL WEIGHT       660 LBS       - INCLUDES MOTOR DRIVER

AT -301 MIXER       YEAST MIX TANK MS301        SHELL MAT'L      A285C           - VOLUME         10000.00 GALLONS     58600
                                                DIAMETER         11.00 FEET      - HEIGHT            15.00 FEET
                                                DRIVER SPEED     52.00 RPM       - DRIVER POWER      40.00 HP
                                                DESIGN TEMP.    250.00 DEG F     - DESIGN PRESS      15.00 PSIG
                                                THICKNESS         0.31 INCHES    - REYNOLDS NO.    1046963
                                                FLUID DEPTH      13.70 FEET      - TOTAL WEIGHT      15900 LBS

CT -301 SCROLL-CON YSTCT301AB (2) ITEM X-200 MATERIAL            CS              - RATE           150000.0 LB/H       741200
                                                DIAMETER         44.00 INCHES    - DRIVER POWER     250.00 HP
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                        08  ETHANOL PURIFICATION 400 UNIT     -  ON GRADE
                                 E Q U I P M E N T    L I S T
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ETHANOL PURIF

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ORIGIN :EQUIPPENT  :          I T E M             :-------------------- D E S I G N   D A T A -------------------: EQUIPMENT:
       :ITEM TYPE  :  D E S C R I P T I O N       :                                                                  : COST $    :
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     -401 SIEVE TRAY BEER COLUMN AS-401         SHELL MAT'L         A 515          - NO. OF TRAYS          16              151400
                                                DIAMETER           12.50 FEET      - HEIGHT             50.00 FEET
                                                DESIGN TEMP.      650.00 DEG F     - DESIGN PRESS       15.00 PSIG
                                                TRAY SPACING       24.00 INCHES    - TRAY MAT'L         4285C
                                                THICKNESS           0.38 INCHES    - TOTAL WEIGHT       78400 LBS

TW -402 SIEVE TRAY RECTIFYING COLUMNAS-402      SHELL MAT'L         A 515          - NO. OF TRAYS          24              142800
                                                DIAMETER           10.00 FEET      - HEIGHT             65.00 FEET
                                                DESIGN TEMP.      650.00 DEG F     - DESIGN PRESS       15.00 PSIG
                                                TRAY SPACING       24.00 INCHES    - TRAY MAT'L         4285C
                                                THICKNESS           0.38 INCHES    - TOTAL WEIGHT       76100 LBS

HT -402 HORIZ-DRUM BEERCOL REFORM MS-402        SHELL MAT'L         CS             - CAPACITY          800.00 GALLONS        4400
                                                DIAMETER            3.50 FEET      - LENGTH             11.00 FEET
                                                DESIGN PRESS       50.00 PSIG      - DESIGN TEMP.      250.00 DEG F
                                                THICKNESS           0.31 INCHES    - TOTAL WEIGHT        2600 LBS

HT -403 HORIZ-DRUM FUSLOIL DECANTR MS-403       SHELL MAT'L         CS             - CAPACITY          870.00 GALLONS        4400
                                                DIAMETER            3.50 FEET      - LENGTH             12.00 FEET
                                                DESIGN PRESS       25.00 PSIG      - DESIGN TEMP.      150.00 DEG F
                                                THICKNESS           0.31 INCHES    - TOTAL WEIGHT        2700 LBS

VT -404 CONE ROOF  MOLSIEVE FEEDTANK MT-404     MATERIAL            CS             - CAPACITY        38000.00 GALLONS       21600
                                                DIAMETER           20.00 FEET      - HEIGHT             16.00 FEET
                                                DESIGN PRESS       0.050 PSIG      - TEMPERATURE       250.00 DEG F
                                                THICKNESS           0.19 INCHES    - TOTAL WEIGHT       17900 LBS
                                                INCLUDES FIELD FAB. BY VENDOR

HT -405 HORIZ-DRUM RECTCOL REFDRUM MS-405       SHELL MAT'L         CS             - CAPACITY         3800.00 GALLONS       10300
                                                DIAMETER            6.00 FEET      - LENGTH             18.00 FEET
                                                DESIGN PRESS       50.00 PSIG      - DESIGN TEMP.      250.00 DEG F
                                                THICKNESS           0.31 INCHES    - TOTAL WEIGHT        6600 LBS

VT -406 CONE ROOF  OILBEER FEEDTANK MT-406      MATERIAL            CS             - CAPACITY        127000.0 GALLONS       43500
                                                DIAMETER           26.00 FEET      - HEIGHT             32.00 FEET
                                                DESIGN PRESS       0.050 PSIG      - TEMPERATURE       200.00 DEG F
                                                TOP THICK.          0.19 INCHES    - BOTTOM THICK        0.25 INCHES
                                                TOTAL WEIGHT       40400 LBS       - INCLUDES FIELD FAB. BY VENDOR

     -401 AVS-MEDIUM BEERCOL BTMSPMP PP401A     MATERIAL            CS             - CAPACITY         1450.00 GPM            7300
                                                HEAD              115.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER       60.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT        1800 LBS       - INCLUDES MOTOR DRIVER

CP -401 AVS-MEDIUM BCOL BTMSPMP PP401S SPARE   MATERIAL            CS             - CAPACITY         1450.00 GPM            7300
                                                HEAD              115.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER       60.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT        1800 LBS       - INCLUDES MOTOR DRIVER

GC -402 CENTRIF-M  SUGSTR VAPCOMP PC-402        MATERIAL            CS             - CAPACITY        32000.00 CFM         1357000
                                                INLET PRESS.       10.00 PSIG      - DISCH. PRESS       65.00 PSIG
                                                DRIVER POWER     7000.00 HP        - DRIVER SPEED     5846.00 RPM
                                                INLET TEMP.        68.00 DEG F     - NO. STAGES             4
                                                TOTAL WEIGHT       89100 LBS       - INCLUDES MOTOR DRIVER

CP -403 AVS-MEDIUM BEERCOL REFPUMP PP-403       MATERIAL            CS             - CAPACITY          220.00 GPM            3800
                                                HEAD              136.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER       15.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         940 LBS       - INCLUDES MOTOR DRIVER

CP -403 AVS-MEDIUM BCOLREFPMP   PP403S SPARE   MATERIAL            CS             - CAPACITY          220.00 GPM            3800
                                                HEAD              136.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER       15.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         940 LBS       - INCLUDES MOTOR DRIVER

CP -404 AVS-MEDIUM WASHRET PUMP PP404A          MATERIAL            CS             - CAPACITY           30.00 GPM            3200
                                                HEAD              136.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER        5.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         730 LBS       - INCLUDES MOTOR DRIVER

CP -404 AVS-MEDIUM WASHRET PUMP PP404S SPARE   MATERIAL            CS             - CAPACITY           30.00 GPM            3200
                                                HEAD              136.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER        5.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         730 LBS       - INCLUDES MOTOR DRIVER

CP -406 AVS-MEDIUM FUSLOIL PUMP PP405A          MATERIAL            CS             - CAPACITY            5.00 GPM            2800
                                                HEAD               90.00 FEET      - TEMPERATURE       120.00 DEG F
                                                DRIVER POWER        3.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         640 LBS       - INCLUDES MOTOR DRIVER

CP -405 AVS-MEDIUM FUSLOIL PUMP PP405S SPARE   MATERIAL            CS             - CAPACITY            5.00 GPM     [illegible]
                                                HEAD               90.00 FEET      - TEMPERATURE     [illegible]
                                                DRIVER POWER        3.00 HP        - SPEED            1800.00 RPM
                                                TOTAL WEIGHT         640 LBS       - INCLUDES MOTOR DRIVER

CP -406 AVS-HIGH   MOLSIVE PUMP PP406A          MATERIAL            CS             - CAPACITY           65.00 GPM     [illegible]
                                                HEAD              260.00 FEET      - TEMPERATURE     [illegible]
                                                DRIVER POWER        7.50 HP        - SPEED           [illegible]
                                                TOTAL WEIGHT         500 LBS       - [illegible]
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                          08  ETHANOL PURIFICATION 400 UNIT    -  ON GRADE
                                 E Q U I P M E N T   L I S T

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:        :           :                         :                                                                     : PURCHASED:
:ORIGIN  :EQUIPMENT  :         I T E M         :-------------------- D E S I G N   D A T A --------------------: EQUIPMENT:
:        :ITEM TYPE  :  D E S C R I P T I O N  :                                                                     : COST $    :
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   -406 AVS-HIGH   MOLSIVE PUMP PP406S SPARE MATERIAL          CS              - CAPACITY         65.00 GPM           2200
                                             HEAD           260.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER     7.50 HP          - SPEED          3600.00 RPM
                                             TOTAL WEIGHT      500 LBS         - INCLUDES MOTOR DRIVER

 CP -407 AVS-MEDIUM RCTCOLBTMPMP PP407A      MATERIAL          CS              - CAPACITY        120.00 GPM           3000
                                             HEAD            90.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER     5.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT      690 LBS         - INCLUDES MOTOR DRIVER

 CP -407 AVS-MEDIUM RCTCOLBTMPMP PP407S SPARE MATERIAL         CS              - CAPACITY        120.00 GPM           3000
                                             HEAD            90.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER     5.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT      690 LBS         - INCLUDES MOTOR DRIVER

 CP -408 AVS-MEDIUM RCTCOLREFPMP PP408A      MATERIAL          CS              - CAPACITY        260.00 GPM           3900
                                             HEAD           136.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER    15.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT      950 LBS         - INCLUDES MOTOR DRIVER

 CP -408 AVS-MEDIUM RCTCOLREFPMP PP408S SPARE MATERIAL         CS              - CAPACITY        260.00 GPM           3900
                                             HEAD           136.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER    15.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT      950 LBS         - INCLUDES MOTOR DRIVER

 CP -409 AVS-MEDIUM DILBEERFDPMP PP409A      MATERIAL          CS              - CAPACITY       1450.00 GPM           7300
                                             HEAD           115.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER    60.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT     1800 LBS         - INCLUDES MOTOR DRIVER

 CP -409 AVS-MEDIUM DILBEERFDPMP PP409S SPARE MATERIAL         CS              - CAPACITY       1450.00 GPM           7300
                                             HEAD           115.00 FEET        - TEMPERATURE     120.00 DEG F
                                             DRIVER POWER    60.00 HP          - SPEED          1800.00 RPM
                                             TOTAL WEIGHT     1800 LBS         - INCLUDES MOTOR DRIVER

 HE -405 FIXED-T-S  BEERCOLCONDENSER TT405    TUBE MAT'L       A 214            - TRANSF. AREA  6000.00 SF           60400
                                             SHELL MAT'L      A285C            - TEMA TYPE        BEM
                                             SHELL PRESS.   150.00 PSIG        - SHELL TEMP.    650.00 DEG F
                                             SHELL DIA.      47.00 INCHES      - SHELL LENGTH    20.00 FEET
                                             TUBE PRESS.    150.00 PSIG        - TUBE TEMP.     650.00 DEG F
                                             TUBE DIA.        1.00 INCHES      - TUBE LENGTH     20.00 FEET
                                             TOTAL WEIGHT    30100 LBS

 HE -409 FIXED-T-S  RECTCOLREBOILER  TT409    TUBE MAT'L       A 214            - NO. SHELLS          2             95800
                                             AREA/SHELL    4550.00 SF          - SHELL MAT'L     A285C
                                             TEMA TYPE         BEM             - SHELL PRESS.   150.00 PSIG
                                             SHELL TEMP.    650.00 DEG F       - SHELL DIA.      41.00 INCHES
                                             SHELL LENGTH    20.00 FEET        - TUBE PRESS.    150.00 PSIG
                                             TUBE TEMP.     650.00 DEG F       - TUBE DIA.        1.00 INCHES
                                             TUBE LENGTH     20.00 FEET        - TOTAL WEIGHT    47400 LBS

 HE -412 FIXED-T-S  FEEDPREHEATER    TT412    TUBE MAT'L       304LS            - TRANSF. AREA  6000.00 SF          187400
                                             SHELL MAT'L      A285C            - TEMA TYPE        BEM
                                             SHELL PRESS.   150.00 PSIG        - SHELL TEMP.    650.00 DEG F
                                             SHELL DIA.      47.00 INCHES      - SHELL LENGTH    20.00 FEET
                                             TUBE PRESS.    150.00 PSIG        - TUBE TEMP.     650.00 DEG F
                                             TUBE DIA.        1.00 INCHES      - TUBE LENGTH     20.00 FEET
                                             TOTAL WEIGHT    28700 LBS

  GZ-401 INSTALLED AS AIR DRYER BY SYSTEM
  COST PER KEMP QUOTE TO BADGER MOL SIEVE PACKAGE UNIT
  AD -401 AIR DRYER  MOLSIVS GZ-401 C=2500000  MATERIAL        CS              - CAPACITY     50000.00 CFM         2137067
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                         05  ETHANOL PURIFICATION 400 UNIT    -  STRUCTURE
                                     E Q U I P M E N T   L I S T

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:        :             :                          :                                                                 : PURCHASED:
 'IGIN :EQUIPMENT :          I T E M           :----------------------- D E S I G N   D A T A ----------------------: EQUIPMENT:
       :ITEM TYPE :  D E S C R I P T I O N     :                                                                 : COST $   :
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VT -401 CYLINDER   DEGASSER DRUM MS-401       SHELL MAT'L        CS               - CAPACITY        3800.00 GALLONS          10500
                                              DIAMETER          6.00 FEET         - HEIGHT            18.00 FEET
                                              DESIGN PRESS     15.00 PSIG         - DESIGN TEMP.     650.00 DEG F
                                              THICKNESS         0.31 INCHES       - TOTAL WEIGHT      6400 LBS

HE -402 FIXEC-T-S  DEGDRMCONDENSER  TT402     TUBE MAT'L        A 214             - TRANSF. AREA    1500.00 SF                18200
                                              SHELL MAT'L       A285C             - TEMA TYPE         BEM
                                              SHELL PRESS.    150.00 PSIG         - SHELL TEMP.      650.00 DEG F
                                              SHELL DIA.       24.00 INCHES       - SHELL LENGTH      20.00 FEET
                                              TUBE PRESS.     150.00 PSIG         - TUBE TEMP.       650.00 DEG F
                                              TUBE DIA.         1.00 INCHES       - TUBE LENGTH       20.00 FEET
                                              TOTAL WEIGHT      8400 LBS

HE -403 FIXEC-T-S  REBOILRS TT403AB (2) ITEM  TUBE MAT'L        A 214             - NO. SHELLS          2                     208400
                                              AREA/SHELL     5000.00 SF           - SHELL MAT'L       A285C
                                              TEMA TYPE         BEM               - SHELL PRESS.     150.00 PSIG
                                              SHELL TEMP.     650.00 DEG F        - SHELL DIA.        43.00 INCHES
                                              SHELL LENGTH     20.00 FEET         - TUBE PRESS.      150.00 PSIG
                                              TUBE TEMP.      650.00 DEG F        - TUBE DIA.          1.00 INCHES
                                              TUBE LENGTH      20.00 FEET         - TOTAL WEIGHT     52000 LBS

HE -406 FIXEC-T-S  BEERCCL VENTCNDSR TT406    TUBE MAT'L        A 214             - NO. SHELLS          2                      77100
                                              AREA/SHELL     3500.00 SF           - SHELL MAT'L       A285C
                                              TEMA TYPE         BEM               - SHELL PRESS.     150.00 PSIG
                                              SHELL TEMP.     650.00 DEG F        - SHELL DIA.        36.00 INCHES
                                              SHELL LENGTH     20.00 FEET         - TUBE PRESS.      150.00 PSIG
                                              TUBE TEMP.      650.00 DEG F        - TUBE DIA.          1.00 INCHES
                                              TUBE LENGTH      20.00 FEET         - TOTAL WEIGHT     37400 LBS

HE -407 FIXEC-T-S  FUSLOIL COOLER   TT407     TUBE MAT'L        A 214             - TRANSF. AREA     300.00 SF                 8200
                                              SHELL MAT'L       A285C             - TEMA TYPE         BEM
                                              SHELL PRESS.    150.00 PSIG         - SHELL TEMP.      650.00 DEG F
                                              SHELL DIA.       12.00 INCHES       - SHELL LENGTH      20.00 FEET
                                              TUBE PRESS.     150.00 PSIG         - TUBE TEMP.       650.00 DEG F
                                              TUBE DIA.         1.00 INCHES       - TUBE LENGTH       20.00 FEET
                                              TOTAL WEIGHT      2700 LBS

    -410 FIXEC-T-S  RECTCCL CONDENSER TT410   TUBE MAT'L        A 214             - TRANSF. AREA    3500.00 SF                38500
                                              SHELL MAT'L       A285C             - TEMA TYPE         BEM
                                              SHELL PRESS.    150.00 PSIG         - SHELL TEMP.      650.00 DEG F
                                              SHELL DIA.       36.00 INCHES       - SHELL LENGTH      20.00 FEET
                                              TUBE PRESS.     150.00 PSIG         - TUBE TEMP.       650.00 DEG F
                                              TUBE DIA.         1.00 INCHES       - TUBE LENGTH       20.00 FEET
                                              TOTAL WEIGHT     18700 LBS


HE -411 FIXEC-T-S  RECTCCL VENTCNDSR TT411    TUBE MAT'L        A 214             - NO. SHELLS          2                      77100
                                              AREA/SHELL     3500.00 SF           - SHELL MAT'L       A285C
                                              TEMA TYPE         BEM               - SHELL PRESS.     150.00 PSIG
                                              SHELL TEMP.     650.00 DEG F        - SHELL DIA.        36.00 INCHES
                                              SHELL LENGTH     20.00 FEET         - TUBE PRESS.      150.00 PSIG
                                              TUBE TEMP.      650.00 DEG F        - TUBE DIA.          1.00 INCHES
                                              TUBE LENGTH      20.00 FEET         - TOTAL WEIGHT     37400 LBS

HE -413 FIXEC-T-S  FEED PREHEATER  TT413      TUBE MAT'L        304LS             - NO. SHELLS          4                     632100
                                              AREA/SHELL     5000.00 SF           - SHELL MAT'L       A285C
                                              TEMA TYPE         BEM               - SHELL PRESS.     150.00 PSIG
                                              SHELL TEMP.     650.00 DEG F        - SHELL DIA.        43.00 INCHES
                                              SHELL LENGTH     20.00 FEET         - TUBE PRESS.      150.00 PSIG
                                              TUBE TEMP.      650.00 DEG F        - TUBE DIA.          1.00 INCHES
                                              TUBE LENGTH      20.00 FEET         - TOTAL WEIGHT     96400 LBS
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                              12  TANKAGE 600 UNIT -  ON GRADE
                              E Q U I P M E N T    L I S T

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       :             :                      :                                                          : PURCHASED:
ORIGIN :EQUIPMENT :          I T E M        :-------------------- D E S I G N   D A T A --------------: EQUIPMENT:
       :ITEM TYPE : D E S C R I P T I O N   :                                                          : COST $    :
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CP -609 AVS-MEDIUM DIESEL FUEL  PP609A       MATERIAL          CS            - CAPACITY          25.00 GPM          3000
                                             HEAD          115.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    3.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     680 LBS        - INCLUDES MOTOR DRIVER

CP -609 AVS-MEDIUM DIESEL FUEL  PP609S SPARE MATERIAL          CS            - CAPACITY          25.00 GPM          3000
                                             HEAD          115.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    3.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     680 LBS        - INCLUDES MOTOR DRIVER

CP -610 AVS-MEDIUM GASOLBLNDNG  PP610A       MATERIAL          CS            - CAPACITY          30.00 GPM          2600
                                             HEAD           70.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    2.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     590 LBS        - INCLUDES MOTOR DRIVER

CP -610 AVS-MEDIUM GASOLBLNDNG  PP610S SPARE MATERIAL          CS            - CAPACITY          30.00 GPM          2600
                                             HEAD           70.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    2.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     590 LBS        - INCLUDES MOTOR DRIVER

HE -604 FIXED-T-S  FERMTANKCOOLER TT604      TUBE MAT'L      A 214           - NO. SHELLS            2            104200
                                             AREA/SHELL   5000.00 SF         - SHELL MAT'L       A285C
                                             TEMA TYPE        BEM            - SHELL PRESS.     150.00 PSIG
                                             SHELL TEMP.   650.00 DEG F      - SHELL DIA.        43.00 INCHES
                                             SHELL LENGTH   20.00 FEET       - TUBE PRESS.      150.00 PSIG
                                             TUBE TEMP.    650.00 DEG F      - TUBE DIA.          1.00 INCHES
                                             TUBE LENGTH    20.00 FEET       - TOTAL WEIGHT      52000 LBS

F  -604 TUBULAR    AIRVENTFILTER GF604       MATERIAL          CS            - RATE             100.00 GPM          4200
                                             PARTIC. SIZE   60.00 MESH       - OPERATION          NONE

AD -603 AIR DRYER  DESC AIR FILTER GF603     MATERIAL          CS            - CAPACITY        1500.00 CFM         35100

CP -607 AVS-HIGH   FIREWATER PMP PP607A      MATERIAL          CS            - CAPACITY         600.00 GPM          5500
                                             HEAD          227.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER   50.00 HP         - SPEED           3600.00 RPM
                                             TOTAL WEIGHT    1300 LBS        - INCLUDES MOTOR DRIVER

    607 AVS-HIGH   FIREWATER PMP PP607S SPAR MATERIAL          CS            - CAPACITY         600.00 GPM          5500
                                             HEAD          227.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER   50.00 HP         - SPEED           3600.00 RPM
                                             TOTAL WEIGHT    1300 LBS        - INCLUDES MOTOR DRIVER

CP -605 AVS-MEDIUM FUSLOILEXPT  PP605A       MATERIAL          CS            - CAPACITY         100.00 GPM          2700
                                             HEAD           70.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    3.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     610 LBS        - INCLUDES MOTOR DRIVER

CP -605 AVS-MEDIUM FUSLOILEXPT  PP605S SPARE MATERIAL          CS            - CAPACITY         100.00 GPM          2700
                                             HEAD           70.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER    3.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT     610 LBS        - INCLUDES MOTOR DRIVER
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VT -609 CONE ROOF  DIESELFUEL TANK MT-609    MATERIAL          CS            - CAPACITY       21000.00 GALLONS     15600
                                             DIAMETER       15.00 FEET       - HEIGHT            16.00 FEET
                                             DESIGN PRESS   0.050 PSIG       - TEMPERATURE       68.00 DEG F
                                             THICKNESS       0.19 INCHES     - TOTAL WEIGHT      11700 LBS
                                             INCLUDES FIELD FAB. BY VENDOR

VT -610 CONE ROOF  GASOLINE STRGTANK MT-610  MATERIAL          CS            - CAPACITY       169700.0 GALLONS     55200
                                             DIAMETER       30.00 FEET       - HEIGHT            32.00 FEET
                                             DESIGN PRESS   0.050 PSIG       - TEMPERATURE       48.00 DEG F
                                             TOP THICK.      0.19 INCHES     - BOTTOM THICK       0.31 INCHES
                                             TOTAL WEIGHT   53300 LBS        - INCLUDES FIELD FAB. BY VENDOR

CP -606 AVS-MEDIUM AZSTRPRFDPMP PP606A       MATERIAL          CS            - CAPACITY         800.00 GPM          5700
                                             HEAD          136.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER   40.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT    1400 LBS        - INCLUDES MOTOR DRIVER

CP -606 AVS-MEDIUM AZSTRPRFDPMP PP606S SPARE MATERIAL          CS            - CAPACITY         800.00 GPM          5700
                                             HEAD          136.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER   40.00 HP         - SPEED           1800.00 RPM
                                             TOTAL WEIGHT    1400 LBS        - INCLUDES MOTOR DRIVER

CP -604 AVS-HIGH   FERMFDPMP PP604A          MATERIAL          CS            - CAPACITY        1550.00 GPM         10300
                                             HEAD          160.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER  100.00 HP         - SPEED           3600.00 RPM
                                             TOTAL WEIGHT    2300 LBS        - INCLUDES MOTOR DRIVER

CP -604 AVS-HIGH   FERMFDPMP PP604S SPARE    MATERIAL          CS            - CAPACITY        1550.00 GPM         10300
                                             HEAD          160.00 FEET       - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER  100.00 HP         - SPEED           3600.00 RPM
                                             TOTAL WEIGHT    2300 LBS        - INCLUDES MOTOR DRIVER
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                              12  TANKAGE 600 UNIT -  ON GRADE
                              E Q U I P M E N T   L I S T

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      :           :                         :                                                          : PURCHASED:
  :IN :EQUIPMENT  :         I T E M         :------------------- D E S I G N   D A T A ---------------: EQUIPMENT:
      :ITEM TYPE  :  D E S C R I P T I O N  :                                                          : COST $   :
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VT -606 CONE ROOF  AZEOSTRPRSRGTANK MT-606   MATERIAL         CS             - CAPACITY       88000.00 GALLONS      35100
                                             DIAMETER         25.00 FEET     - HEIGHT            24.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                             TOP THICK.        0.19 INCHES   - BOTTOM THICK       0.25 INCHES
                                             TOTAL WEIGHT     31900 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -604 CONE ROOF  FERMNTFEEDTANK MT604      MATERIAL         CS             - CAPACITY       127000.0 GALLONS      43500
                                             DIAMETER         26.00 FEET     - HEIGHT            32.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURF       68.00 DEG F
                                             TOP THICK.        0.19 INCHES   - BOTTOM THICK       0.25 INCHES
                                             TOTAL WEIGHT     40400 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -601 CONE ROOF  PROSTRTK MT601AS (2) ITEM MATERIAL         CS             - CAPACITY       510000.0 GALLONS     251200
                                             DIAMETER         52.00 FEET     - HEIGHT            32.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                             TOP THICK.        0.25 INCHES   - BOTTOM THICK       0.38 INCHES
                                             TOTAL WEIGHT    135200 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -608 CONE ROOF  SLOPS TANK MT608          MATERIAL         CS             - CAPACITY       127000.0 GALLONS      45800
                                             DIAMETER         30.00 FEET     - HEIGHT            24.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                             TOP THICK.        0.19 INCHES   - BOTTOM THICK       0.25 INCHES
                                             TOTAL WEIGHT     43500 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -607 CONE ROOF  FIRE WATER TANK MT-607    MATERIAL         CS             - CAPACITY       510000.0 GALLONS     125600
                                             DIAMETER         52.00 FEET     - HEIGHT            32.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                             TOP THICK.        0.25 INCHES   - BOTTOM THICK       0.38 INCHES
                                             TOTAL WEIGHT    135200 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -605 CONE ROOF  FUSELOILSTRG MT605        MATERIAL         CS             - CAPACITY       42000.00 GALLONS      22800
                                             DIAMETER         21.00 FEET     - HEIGHT            16.00 FEET
                                             DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                             THICKNESS         0.19 INCHES   - TOTAL WEIGHT      19200 LBS
                                             INCLUDES FIELD FAB. BY VENDOR

(    601 AVS-MEDIUM ETOHPROD PP601AB (2) ITEM MATERIAL        CS             - CAPACITY         525.00 GPM          7600
                                             HEAD             70.00 FEET     - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER     15.00 HP       - SPEED           1800.00 RPM
                                             TOTAL WEIGHT       920 LBS      - INCLUDES MOTOR DRIVER

CP -601 AVS-MEDIUM ETOHPROD  PP601S SPARE    MATERIAL         CS             - CAPACITY         525.00 GPM          3800
                                             HEAD             70.00 FEET     - TEMPERATURE      120.00 DEG F
                                             DRIVER POWER     15.00 HP       - SPEED           1800.00 RPM
                                             TOTAL WEIGHT       920 LBS      - INCLUDES MOTOR DRIVER
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WASTE TRT

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                                  13  WASTE TREATMENT 700 UNIT -  ON GRADE
                                      E Q U I P M E N T    L I S T

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*         *           *                             *                                                        : PURCHASED:
 IGIN  :EQUIPMENT :            I T E M              :------------------- D E S I G N   D A T A ------------------: EQUIPMENT:
       :ITEM TYPE :  D E S C R I P T I O N          :                                                        : COST $    :
-**********************************************************************************************************************
VT -701 CYLINDER   HOTWELL DECANTER MS701      SHELL MAT'L      A285C          - CAPACITY       27200.00 GALLONS      98500
                                               DIAMETER         11.50 FEET     - HEIGHT            35.00 FEET
                                               DESIGN PRESS     15.00 PSIG     - DESIGN TEMP.     200.00 DEG F
                                               CLAD. THICK.      0.13 INCHES   - CLAD MAT'L       304L
                                               THICKNESS         0.19 INCHES   - TOTAL WEIGHT     31800 LBS

VT -702 STORAGE    MIXED SOLVENT TANK MT-702   SHELL MAT'L      CS             - CAPACITY      169200.0 GALLONS       52900
                                               DIAMETER         30.00 FEET     - HEIGHT            32.00 FEET
                                               DESIGN PRESS     0.050 PSIG     - DESIGN TEMP.      68.00 DEG F
                                               AVG. THICK.       0.25 INCHES   - TOTAL WEIGHT     50100 LBS
                                               INCLUDES FIELD FAB. BY VENDOR

VT -707 OPEN TOP   BIOTREATER MT707            SHELL MAT'L      EPLCS          - CAPACITY      350000.0 GALLONS       99300
                                               DIAMETER         50.00 FEET     - HEIGHT            24.00 FEET
                                               DESIGN TEMP.     68.00 DEG F    - THICKNESS          0.25 INCHES
                                               TOTAL WEIGHT     63500 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -708 CONE ROOF  FILTER FEED TANK MS708      MATERIAL         EPLCS          - CAPACITY       30000.00 GALLONS      27800
                                               DIAMETER         16.00 FEET     - HEIGHT            20.00 FEET
                                               DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                               THICKNESS         0.19 INCHES   - TOTAL WEIGHT     14300 LBS
                                               INCLUDES FIELD FAB. BY VENDOR

CP -716 AVS-MEDIUM FINEFFPMP PP716A            MATERIAL           CI           - CAPACITY         700.00 GPM            3900
                                               HEAD           .  90.00 FEET    - TEMPERATURE      120.00 DEG F
                                               DRIVER POWER     20.00 HP       - SPEED           1800.00 RPM
                                               TOTAL WEIGHT      1100 LBS      - INCLUDES MOTOR DRIVER

CP -716 AVS-PEDIUM FINEFFPMP PP716S      SPARE MATERIAL           CI           - CAPACITY         700.00 GPM            3900
                                               HEAD             90.00 FEET     - TEMPERATURE      120.00 DEG F
                                               DRIVER POWER     20.00 HP       - SPEED           1800.00 RPM
                                               TOTAL WEIGHT      1100 LBS      - INCLUDES MOTOR DRIVER

FN -717 ROT-BLOWER LPVENTBLOWER PB717A         MATERIAL           CS           - CAPACITY        2400.00 CFM            8100
                                               DISCH. PRESS      5.00 PSIG     - SPEED           1800.00 RPM
                                               FAN POWER        75.00 HP       - TOTAL WEIGHT      2400 LBS

   -717 ROT-BLOWER LPVENTBLOWER PB717S SPARE   MATERIAL           CS           - CAPACITY        2400.00 CFM            8100
                                               DISCH. PRESS      5.00 PSIG     - SPEED           1800.00 RPM
                                               FAN POWER        75.00 HP       - TOTAL WEIGHT      2400 LBS

HE -705 FIXEC-T-S  STILLAGE COOLER TT705       TUBE MAT'L        304LS         - NO. SHELLS           2                115800
                                               AREA/SHELL      5000.00 SF      - SHELL MAT'L      A285C
                                               TEMA TYPE          BEM          - SHELL PRESS.     150.00 PSIG
                                               SHELL TEMP.     650.00 DEG F    - SHELL DIA.        43.00 INCHES
                                               SHELL LENGTH     20.00 FEET     - TUBE PRESS.      150.00 PSIG
                                               TUBE TEMP.      650.00 DEG F    - TUBE DIA.          1.00 INCHES
                                               TUBE LENGTH      20.00 FEET     - TOTAL WEIGHT     48200 LBS

HE -706 FIXEC-T-S  SOLVENT COOLER TT706        TUBE MAT'L       A 214          - TRANSF. AREA      40.00 SF              6500
                                               SHELL MAT'L      A285C          - TEMA TYPE         BEM
                                               SHELL PRESS.    150.00 PSIG     - SHELL TEMP.      650.00 DEG F
                                               SHELL DIA.        6.00 INCHES   - SHELL LENGTH      20.00 FEET
                                               TUBE PRESS.     150.00 PSIG     - TUBE TEMP.       650.00 DEG F
                                               TUBE DIA.         1.00 INCHES   - TUBE LENGTH       20.00 FEET
                                               TOTAL WEIGHT      1100 LBS

F  -704 ROTY-DRUM  ROTARY FILTER GF704         MATERIAL           CS           - AREA             100.00 SF             38300
                                               SPEED          1800.00 RPM      - DRIVER POWER       3.00 HP
                                               TOTAL WEIGHT      6400 LBS

T  -708 THICKENER  SEC CLARIFIER GV708         MATERIAL           CS           - DIAMETER          80.00 FEET           101300
                                               TOTAL WEIGHT     35100 LBS

AG -712 PECH-SEAL  MS708 AGITATOR GA712        MATERIAL           CS           - DRIVER POWER       5.00 HP              2300
                                               SPEED             0.00 RPM      - TOTAL WEIGHT       300 LBS

CCST-KNCWN INFORMATION FCR 3 ITEMS BELOW
OBTAINED FROP BAGGER
VT -703 CONE ROOF  MT703 EQUALTNK C=204600     MATERIAL           CS           - CAPACITY      600000.0 GALLONS      174896
                                               DIAMETER         51.00 FEET     - HEIGHT            40.00 FEET
                                               DESIGN PRESS     0.050 PSIG     - TEMPERATURE       68.00 DEG F
                                               TOP THICK.        0.25 INCHES   - BOTTOM THICK       0.44 INCHES
                                               TOTAL WEIGHT    154500 LBS      - INCLUDES FIELD FAB. BY VENDOR

VT -704 CYLIADER   MT704 ANRBRCTR C=354700     SHELL MAT'L        CS           - CAPACITY      160000.0 GALLONS      303207
                                               DIAMETER         25.00 FEET     - HEIGHT            43.50 FEET
                                               DESIGN PRESS     15.00 PSIG     - DESIGN TEMP.     650.00 DEG F
                                               THICKNESS         0.44 INCHES   - TOTAL WEIGHT    156400 LBS
                                               INCLUDES FIELD FAB. BY VENDOR

VT -705 CYLIADER   MT705 SURGDRUM  C=21400     SHELL MAT'L        CS           - CAPACITY       10000.00 GALLONS      18291
                                               DIAMETER         10.00 FEET     - HEIGHT            17.00 FEET
                                               DESIGN PRESS     15.00 PSIG     - DESIGN TEMP.     650.00 DEG F
                                               THICKNESS         0.31 INCHES   - TOTAL WEIGHT     11600 LBS
```

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                              14  WASTE TREATMENT 700 UNIT -  STRUCTURE
                                     E Q U I P M E N T    L I S T

*******************************************************************************************************************
:          :            :                            :                                                       : PURCHASED:
   IGIN  :EQUIPMENT :            I T E M             :--------------------- D E S I G N   D A T A --------------------: EQUIPMENT:
         :ITEM TYPE :  D E S C R I P T I O N  :                                                       : COST $    :
*******************************************************************************************************************
VT -710 CYLINDER   LPVENT KO DRUM MS710 KO     SHELL MAT'L        CS                - CAPACITY         475.00 GALLONS          4600
                                               DIAMETER          3.00 FEET          - HEIGHT             9.00 FEET
                                               DESIGN PRESS     15.00 PSIG          - DESIGN TEMP.     150.00 DEG F
                                               THICKNESS         0.31 INCHES        - TOTAL WEIGHT       2200 LBS

EJ -704 TWO STAGE  VACUUM SYSTEM PE704         MATERIAL           SS                - AIR CAPACITY     115.00 LB/H             8000
                                               PRESSURE        100.00 MM HG

HE -701 FIXED-T-S  EVEFFHTRS 701 702 (2) ITEM TUBE MAT'L        A 214               - NO. SHELLS            4                514800
                                               AREA/SHELL     6500.00 SF            - SHELL MAT'L       A285C
                                               TEMA TYPE          BEM               - SHELL PRESS.     150.00 PSIG
                                               SHELL TEMP.     650.00 DEG F         - SHELL DIA.        48.00 INCHES
                                               SHELL LENGTH     20.00 FEET          - TUBE PRESS.      150.00 PSIG
                                               TUBE TEMP.      650.00 DEG F         - TUBE DIA.          1.00 INCHES
                                               TUBE LENGTH      20.00 FEET          - TOTAL WEIGHT     129600 LBS

HE -703 FIXED-T-S  3RDEFFHTR TT703            TUBE MAT'L        304LS               - NO. SHELLS            4                513100
                                               AREA/SHELL     6500.00 SF            - SHELL MAT'L       A285C
                                               TEMA TYPE          BEM               - SHELL PRESS.     150.00 PSIG
                                               SHELL TEMP.     650.00 DEG F         - SHELL DIA.        48.00 INCHES
                                               SHELL LENGTH     20.00 FEET          - TUBE PRESS.      150.00 PSIG
                                               TUBE TEMP.      650.00 DEG F         - TUBE DIA.          1.00 INCHES
                                               TUBE LENGTH      20.00 FEET          - TOTAL WEIGHT     120400 LBS

HE -704 FIXED-T-S  EVAP CONDNSR TT704         TUBE MAT'L        304LS               - NO. SHELLS            5                473500
                                               AREA/SHELL     5600.00 SF            - SHELL MAT'L       A285C
                                               TEMA TYPE          BEM               - SHELL PRESS.     150.00 PSIG
                                               SHELL TEMP.     650.00 DEG F         - SHELL DIA.        45.00 INCHES
                                               SHELL LENGTH     20.00 FEET          - TUBE PRESS.      150.00 PSIG
                                               TUBE TEMP.      650.00 DEG F         - TUBE DIA.          1.00 INCHES
                                               TUBE LENGTH      20.00 FEET          - TOTAL WEIGHT     131000 LBS

VT -701 CYLINDER   1STEFF EVAP GE701          SHELL MAT'L        CS                - CAPACITY       20300.00 GALLONS         34300
                                               DIAMETER         12.00 FEET          - HEIGHT            24.00 FEET
                                               DESIGN PRESS     25.00 PSIG          - DESIGN TEMP.     300.00 DEG F
                                               THICKNESS         0.31 INCHES        - TOTAL WEIGHT      23100 LBS

   -702 CYLINDER   2NDEFF EVAP GE702          SHELL MAT'L        CS                - CAPACITY       34400.00 GALLONS         58000
                                               DIAMETER         15.00 FEET          - HEIGHT            26.00 FEET
                                               DESIGN PRESS     25.00 PSIG          - DESIGN TEMP.     250.00 DEG F
                                               THICKNESS         0.38 INCHES        - TOTAL WEIGHT      35300 LBS
                                               INCLUDES FIELD FAB. BY VENDOR
                                                                 -----------                                              ------
VT -706 CYLINDER   MT706 KOPOTOFFGASC=5000    SHELL MAT'L        CS.               - CAPACITY        1500.00 GALLONS          7600
                                               DIAMETER          6.00 FEET          - HEIGHT             7.00 FEET
                                               DESIGN PRESS     15.00 PSIG          - DESIGN TEMP.     650.00 DEG F
                                               THICKNESS         0.31 INCHES        - TOTAL WEIGHT       3800 LBS

VT -703 CYLINDER   3RDEFF EVAP GE703          SHELL MAT'L        CS                - CAPACITY       56400.00 GALLONS         90800
                                               DIAMETER         20.00 FEET          - HEIGHT            24.00 FEET
                                               DESIGN PRESS     25.00 PSIG          - DESIGN TEMP.     250.00 DEG F
                                               THICKNESS         0.44 INCHES        - TOTAL WEIGHT      54300 LBS
                                               INCLUDES FIELD FAB. BY VENDOR
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UTIL
1~

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                              15  UTILITIES 800 UNIT    -  ON GRADE
                                  E Q U I P M E N T    L I S T

*******************************************************************************************************************
 :        :            :                           :                                                  : PURCHASED:
   GIN  :EQUIPMENT :            I T E M          :------------------- D E S I G N   D A T A -------------------: EQUIPMENT:
        :ITEM TYPE : D E S C R I P T I O N     :                                                  : COST $   :
*******************************************************************************************************************
VT -801 CONE ROOF   PROCESS WATER TANK MT801  MATERIAL        CS             - CAPACITY       585000.0 GALLONS      137400
                                              DIAMETER       50.00 FEET      - HEIGHT            40.00 FEET
                                              DESIGN PRESS   0.050 PSIG      - TEMPERATURE       68.00 DEG F
                                              TOP THICK.      0.25 INCHES    - BOTTOM THICK       0.44 INCHES
                                              TOTAL WEIGHT  144800 LBS       - INCLUDES FIELD FAB. BY VENDOR

VT -802 CYLINDER    BLWDN FLASH DRUM MS802    SHELL MAT'L     CS             - CAPACITY         530.00 GALLONS        5600
                                              DIAMETER        3.00 FEET      - HEIGHT            10.00 FEET
                                              DESIGN PRESS   50.00 PSIG      - DESIGN TEMP.     350.00 DEG F
                                              THICKNESS       0.31 INCHES    - TOTAL WEIGHT       2500 LBS

VT -803 CYLINDER    HYDRAZINE DRUM MS803      SHELL MAT'L     316L           - CAPACITY         250.00 GALLONS        7200
                                              DIAMETER        3.00 FEET      - HEIGHT             4.70 FEET
                                              DESIGN PRESS   10.00 PSIG      - DESIGN TEMP.     200.00 DEG F
                                              THICKNESS       0.19 INCHES    - TOTAL WEIGHT       1300 LBS

HT -804 HORIZ-DRUM CONDSURGE DRUM MS804       SHELL MAT'L     CS             - CAPACITY       18000.00 GALLONS       20800
                                              DIAMETER       10.00 FEET      - LENGTH            30.00 FEET
                                              DESIGN PRESS   15.00 PSIG      - DESIGN TEMP.     250.00 DEG F
                                              THICKNESS       0.31 INCHES    - TOTAL WEIGHT      17800 LBS

VT -805 OPEN TOP    BACKWASH TRANS TNK MF805  SHELL MAT'L     CS             - CAPACITY       12000.00 GALLONS       10200
                                              DIAMETER       22.00 FEET      - HEIGHT             4.00 FEET
                                              DESIGN TEMP.   68.00 DEG F     - THICKNESS          0.19 INCHES
                                              TOTAL WEIGHT    7100 LBS       - INCLUDES FIELD FAB. BY VENDOR

VT -806 CYLINDER    AIRRCS MS806 807 (2) ITEM SHELL MAT'L     CS             - CAPACITY        2400.00 GALLONS       24400
                                              DIAMETER        5.00 FEET      - HEIGHT            16.00 FEET
                                              DESIGN PRESS  150.00 PSIG      - DESIGN TEMP.     150.00 DEG F
                                              THICKNESS       0.56 INCHES    - TOTAL WEIGHT       8000 LBS

CP -802 CENTRIF-M   PROCWATR PMP PP802A       MATERIAL        CI             - CAPACITY        2400.00 GPM            5900
                                              HEAD           70.00 FEET      - DESIGN TEMP.     120.00 DEG F
                                              DRIVER SPEED 1800.00 RPM       - DRIVER POWER      60.00 HP
                                              TOTAL WEIGHT    1800 LBS       - INCLUDES MOTOR DRIVER

 ` -802 CENTRIF-M   PROCWATR PMP PP802S SPARE MATERIAL        CI             - CAPACITY        2400.00 GPM            5900
                                              HEAD           70.00 FEET      - DESIGN TEMP.     120.00 DEG F
                                              DRIVER SPEED 1800.00 RPM       - DRIVER POWER      60.00 HP
                                              TOTAL WEIGHT    1800 LBS       - INCLUDES MOTOR DRIVER

CP -803 CENTRIF-M   PRCWATCIRPMP PP803A       MATERIAL        CI             - CAPACITY        5000.00 GPM           27100
                                              HEAD          136.00 FEET      - DESIGN TEMP.     120.00 DEG F
                                              DRIVER SPEED 1800.00 RPM       - DRIVER POWER     250.00 HP
                                              TOTAL WEIGHT    4400 LBS       - INCLUDES MOTOR DRIVER


CP -803 CENTRIF-M   PRCWATCIRPMP PP803S SPARE MATERIAL        CI             - CAPACITY        5000.00 GPM           27100
                                              HEAD          136.00 FEET      - DESIGN TEMP.     120.00 DEG F
                                              DRIVER SPEED 1800.00 RPM       - DRIVER POWER     250.00 HP
                                              TOTAL WEIGHT    4400 LBS       - INCLUDES MOTOR DRIVER

CP -804 CENTRIF-M   BWSHFDPP PP804AB (2) ITEM MATERIAL        CI             - CAPACITY        6000.00 GPM           21200
                                              HEAD           48.00 FEET      - DESIGN TEMP.     120.00 DEG F
                                              DRIVER SPEED 1800.00 RPM       - DRIVER POWER     100.00 HP
                                              TOTAL WEIGHT    3100 LBS       - INCLUDES MOTOR DRIVER

CP -805 AVS-MEDIUM BWSTRNPP PP805AB (2) ITEM  MATERIAL        CI             - CAPACITY          50.00 GPM            4000
                                              HEAD           48.00 FEET      - TEMPERATURE      120.00 DEG F
                                              DRIVER POWER    1.00 HP        - SPEED           1800.00 RPM
                                              TOTAL WEIGHT     500 LBS       - INCLUDES MOTOR DRIVER

CP -806 AVS-MEDIUM BLOWCCWNPMP PP806A         MATERIAL        CI             - CAPACITY          50.00 GPM            2100
                                              HEAD           57.00 FEET      - TEMPERATURE      120.00 DEG F
                                              DRIVER POWER    1.50 HP        - SPEED           1800.00 RPM
                                              TOTAL WEIGHT     540 LBS       - INCLUDES MOTOR DRIVER

CP -806 AVS-MEDIUM BLOWCCWNPMP PP806S SPARE   MATERIAL        CI             - CAPACITY          50.00 GPM            2100
                                              HEAD           57.00 FEET      - TEMPERATURE      120.00 DEG F
                                              DRIVER POWER    1.50 HP        - SPEED           1800.00 RPM
                                              TOTAL WEIGHT     540 LBS       - INCLUDES MOTOR DRIVER

CP -807 AVS-MEDIUM HYDRAZINE TRANSPMP PP807   MATERIAL        SS316          - CAPACITY           5.00 GPM            3700
                                              HEAD           45.00 FEET      - TEMPERATURE      120.00 DEG F
                                              DRIVER POWER    1.50 HP        - SPEED           1800.00 RPM
                                              TOTAL WEIGHT     520 LBS       - INCLUDES MOTOR DRIVER

   -808 CENTRIF-M   HP BFWPMPUMP PP808A       MATERIAL        CS             - CAPACITY        1700.00 GPM          101000
                                              HEAD         2838.00 FEET      - DESIGN TEMP.    [illegible]
                                              DRIVER SPEED 3600.00 RPM       - DRIVER POWER    1500.00 HP
                                              TOTAL WEIGHT   19700 LBS       - INCLUDES MOTOR DRIVER
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                    15  UTILITIES 800 UNIT    -  ON GRADE
                          E Q U I P M E N T    L I S T

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:          :              :                             :                                                        : PURCHASED:
 'IGIN :EQUIPMENT :             I T E M               :-------------------- D E S I G N   D A T A -------------------: EQUIPMENT:
       :ITEM TYPE :  D E S C R I P T I O N            :                                                        : COST $    :
**********************************************************************************************************************
CP -809 AVS-MEDIUM DEARFDPUMP     PP809S SPARE MATERIAL          CI              - CAPACITY         1700.00 GPM          4900
                                               HEAD              45.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      25.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1300 LBS       - INCLUDES MOTOR DRIVER

CP -810 AVS-MEDIUM TURBCONDPMP   PP810A        MATERIAL          CI              - CAPACITY          650.00 GPM          3900
                                               HEAD              90.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      20.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1100 LBS       - INCLUDES MOTOR DRIVER

CP -810 AVS-MEDIUM TURBCONDPMP   PP810S SPARE  MATERIAL          CI              - CAPACITY          650.00 GPM          3900
                                               HEAD              90.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      20.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1100 LBS       - INCLUDES MOTOR DRIVER

GC -811 RECIP-MOTR AIR COMPRESSOR PC811        MATERIAL          CS              - CAPACITY         1000.00 CFM        203800
                                               INLET PRESS.       0.50 PSIG      - DISCH. PRESS      125.00 PSIG
                                               DRIVER POWER     200.00 HP        - DRIVER SPEED      514.00 RPM
                                               INLET TEMP.       68.00 DEG F     - NO. STAGES              2
                                               TOTAL WEIGHT      29000 LBS       - INCLUDES MOTOR DRIVER

CP -812 CENTRIF-M  CWCIRC  PP812A-H (8) ITEM   MATERIAL          CI              - CAPACITY         7500.00 GPM        279200
                                               HEAD             136.00 FEET      - DESIGN TEMP.      120.00 DEG F
                                               DRIVER SPEED    1800.00 RPM       - DRIVER POWER      350.00 HP
                                               TOTAL WEIGHT       6000 LBS       - INCLUDES MOTOR DRIVER

CP -813 AVS-MEDIUM WELLWATR PP813AB (2) ITEM   MATERIAL          CI              - CAPACITY         2000.00 GPM         12000
                                               HEAD              57.00 FEET      - TEMPERATURE       170.00 DEG F
                                               DRIVER POWER      40.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1600 LBS       - INCLUDES MOTOR DRIVER

CP -813 AVS-MEDIUM WELLWATER PP813S   SPARE    MATERIAL          CI              - CAPACITY         2000.00 GPM          6000
                                               HEAD              57.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      40.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1600 LBS       - INCLUDES MOTOR DRIVER

VT -801 CONE ROOF  SAND FILTER GF801           MATERIAL          CS              - CAPACITY        54000.00 GALLONS     36300
                                               DIAMETER          34.00 FEET      - HEIGHT              8.00 FEET
                                               DESIGN PRESS      0.050 PSIG      - TEMPERATURE        68.00 DEG F
                                               THICKNESS          0.19 INCHES    - TOTAL WEIGHT      34800 LBS
                                               INCLUDES FIELD FAB. BY VENDOR

VT -805 CYLINDER   COND COLLTNK GU805          SHELL MAT'L       CS              - CAPACITY         2000.00 GALLONS      8800
                                               DIAMETER           6.00 FEET      - HEIGHT              9.40 FEET
                                               DESIGN PRESS      15.00 PSIG      - DESIGN TEMP.      100.00 DEG F
                                               THICKNESS          0.31 INCHES    - TOTAL WEIGHT       4400 LBS


CP -808 CENTRIF-M  HP BFWPMPUMP PP808S SPARE   MATERIAL          CS              - CAPACITY         1700.00 GPM        103000
                                               HEAD            2830.00 FEET      - DESIGN TEMP.      120.00 DEG F
                                               DRIVER SPEED    3600.00 RPM       - DRIVER POWER     1500.00 HP
                                               TOTAL WEIGHT      19700 LBS       - INCLUDES MOTOR DRIVER

CP -809 AVS-MEDIUM DEARFDPUMP     PP809A       MATERIAL          CI              - CAPACITY         1700.00 GPM          4900
                                               HEAD              45.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      25.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1300 LBS       - INCLUDES MOTOR DRIVER


LIN-805 OTHER                                  LINING MAT'L      REPRB           - LINING AREA      2000.00 SF          38400
                                               LINING THICK       1.00 INCHES    - ADJUSTMENT          4.00

CP -805 AVS-MEDIUM PUMPS GU805AB     (2) ITEM  MATERIAL          SS316           - CAPACITY         1700.00 GPM         19200
                                               HEAD              70.00 FEET      - TEMPERATURE       120.00 DEG F
                                               DRIVER POWER      40.00 HP        - SPEED            1800.00 RPM
                                               TOTAL WEIGHT       1600 LBS       - INCLUDES MOTOR DRIVER

VT -807 CYLINDER   TK GU807 808 809 (3) ITEM   SHELL MAT'L       316L            - CAPACITY          150.00 GALLONS     22500
                                               DIAMETER           3.00 FEET      - HEIGHT              2.80 FEET
                                               DESIGN PRESS      15.00 PSIG      - DESIGN TEMP.      150.00 DEG F
                                               THICKNESS          0.19 INCHES    - TOTAL WEIGHT       1100 LBS

P  -807 DIAPHRAGM  PPSGU807 808 809 (6) ITEM   MATERIAL          SS316           - CAPACITY            5.00 GPM         10800
                                               DRIVER POWER       0.13 HP        - SPEED            1800.00 RPM
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                                  15  UTILITIES 800 UNIT   -  ON GRADE
                                      E Q U I P M E N T    L I S T

 ************************************************************************************************************
 *       *          *                          *                                                  * PURCHASED:
 ORIGIN  *EQUIPMENT *         I T E M          *------------------- D E S I G N   D A T A --------------------* EQUIPMENT:
 *       *ITEM TYPE * D E S C R I P T I O N    *                                                  * COST $    :
 ************************************************************************************************************
STB-801 STM BOILER STMBLRS  HB801AB (2) ITEM MATERIAL          CS              - CAPACITY      400000.0 LB/H        3072000
                                             PRESSURE     1000.00 PSIG         - SUPERHEAT        300.00 DEG F
                                             TOTAL WEIGHT   256400 LBS         - INCLUDES FIELD FAB. BY VENDOR

WTS-803 DEMINERAL  DEMINZS  GU803AB C=850000 MATERIAL          CS              - CAPACITY      15000.00 GPM          726603
                                             TOTAL WEIGHT    18400 LBS         - PACKAGED SYSTEM

VT -806 CYLINDER   DEAERATOR GV806  C=120000 SHELL MAT'L       CS              - CAPACITY      17000.00 GALLONS      102579
                                             DIAMETER         12.00 FEET       - HEIGHT           20.00 FEET
                                             DESIGN PRESS     15.00 PSIG       - DESIGN TEMP.    650.00 DEG F
                                             THICKNESS         0.31 INCHES     - TOTAL WEIGHT     21200 LBS

D  -801 SPRAY      FLAKT  (6) ITEM  C=400000 MATERIAL          CS              - EVAP. RATE     3500.00 LB/H        2051585
                                             DIAMETER         14.00 FEET


AD -810 AIR DRYER  INST AIR DRYER GY810      MATERIAL          CS              - CAPACITY        600.00 CFM           21000

COST-KNOWN INFORMATION FROM BADGER USED ONLY
AS INDICATED IN ITEM SPECS  .

GU-803AB $425000 EACH PERMUTIT
GT-812 COOLING TOWER MTL-$400000 L-$332000 FLD ERECT
GZ-811 TURBOGENERATOR $4800000 ALL SHOP-FAB PARTS

HB-801AB STEAM BOILERS
FIELD ERECTED
FOUNDATION CONDENSER ADD $800000
BOILER A MTL-$5200000 L-$1050000
BOILER B MTL-$5200000 L-$1050000

FLAKT SYSTEM FABRICATED PIECES $2400000
INSTALLED AS MULTIPLE SPRAY DRYERS BY SYSTEM

 ""ILERS AND AUXILIARIES INSTALLED AND COSTED
   ICARUS SYSTEM BADGER COSTS FOR REFERENCE ONLY
(  -811 TURBO-GEN  TURBO GENERATOR GZ811     MATERIAL          CS              - CAPACITY      44500.00 KVA         5417300

 CTW-812 COOLING-WP COOLING TOWER SYST GT812  MATERIAL         A285C           - CAPACITY      60000.00 GPM         1067600
                                              TEMP. RANGE     30.00 DEG F      - APPR. GRAD.      10.00 DEG F
                                              WET BULB TMP    74.00 DEG F      - POWER/FAN       125.00 HP
                                              NO. OF FANS       10             - POWER/PUMP      400.00 HP
                                              NO. OF PUMPS       3             - TOTAL WEIGHT    186500 LBS
                                              INCLUDES FIELD FAB. BY VENDOR
D-1      CLOSED   GATE HOUSE                 CS       LENGTH            8.00 FEET          1164.       67        947.         2111.
                                                      WIDTH             8.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

D-2      CLOSED   GATE HOUSE                 CS       LENGTH            8.00 FEET          1164.       62        947.         2111.
                                                      WIDTH             8.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

D-3      OFFICE   ADMINISTRATION BUILDING    CS       LENGTH          100.00 FEET         92819.     4689      71526.       164345.
                                                      WIDTH            30.00 FEET
                                                      HEIGHT           10.00 FEET
                                                      NO. LEVELS          1

D-4      SHOP     MAINTENANCE SHOP           CS       LENGTH          100.00 FEET         86890.     4650      70677.       157567.
                                                      WIDTH            50.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

D-5      WARE     WAREHOUSE                  CS       LENGTH          200.00 FEET        170926.     9313     137346.       308272.
                                                      WIDTH            70.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

D-6      CLOSED   PUMP HOUSE                 CS       LENGTH           30.00 FEET         16366.      875      13315.        29681.
                                                      WIDTH            30.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

         CLOSED   WEIGH SCALE HOUSE          CS       LENGTH           25.00 FEET         11365.      607       9247.        20612.
                                                      WIDTH            25.00 FEET
                                                      HEIGHT           20.00 FEET
                                                      NO. LEVELS          1

D-8      CONTRL   CONTROL BLDG/MCC           CS       LENGTH          100.00 FEET        122174.     5829      86993.   [illegible]
                                                      WIDTH            25.00 FEET
                                                      HEIGHT           10.00 FEET
                                                      NO. LEVELS          1
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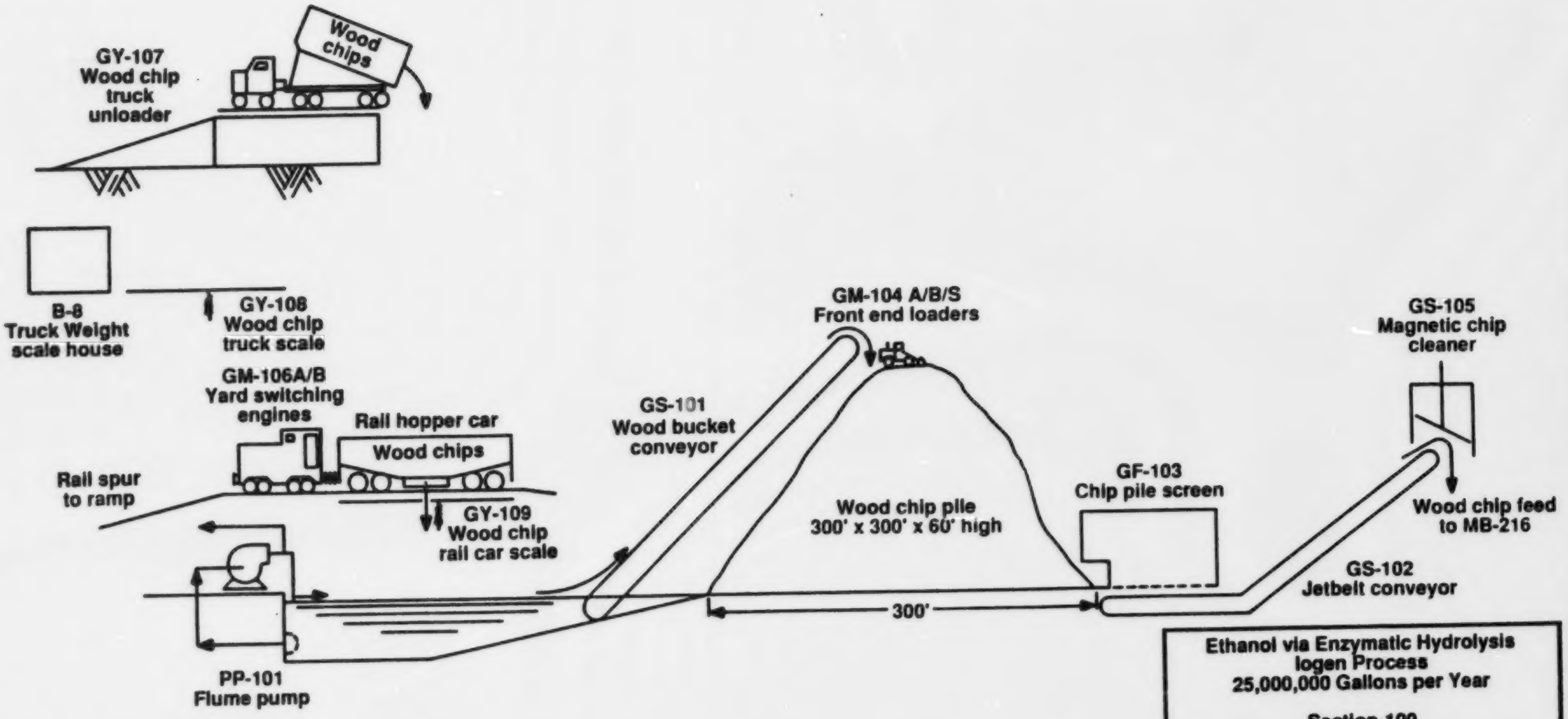
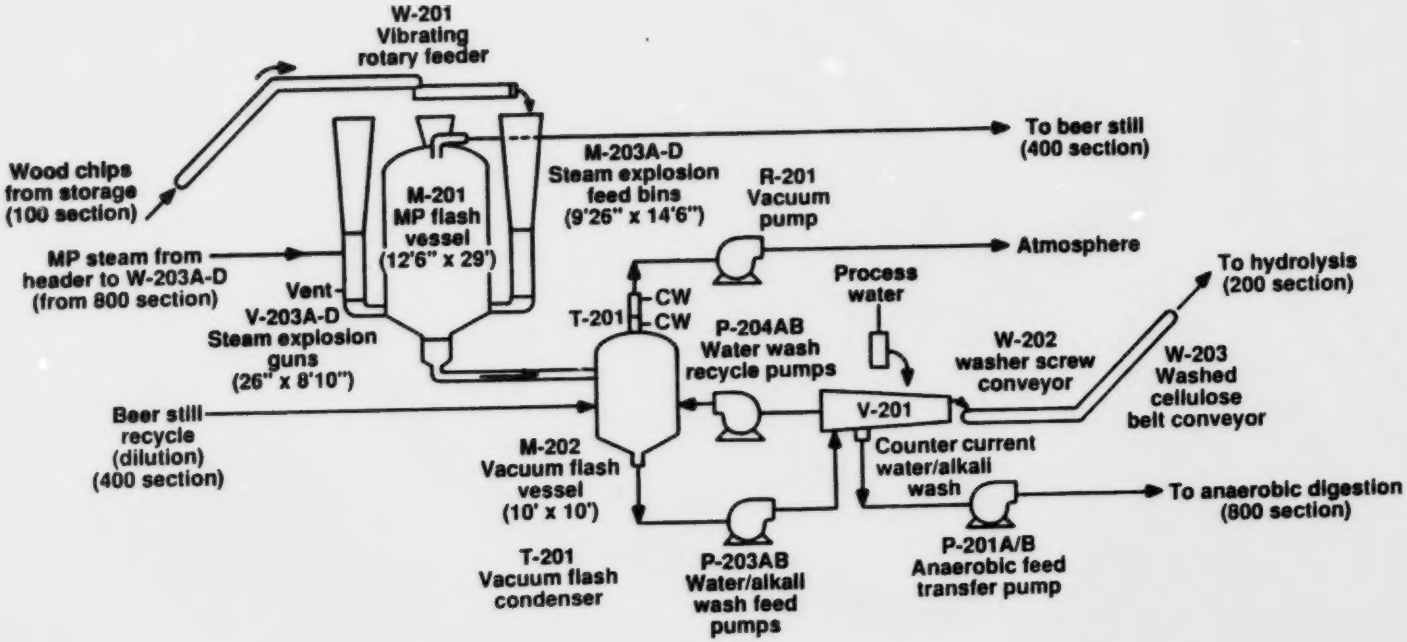

GY-107
Wood chip
truck
unloader
Wood chips
B-8
Truck Weight
scale house
GY-108
Wood chip
truck scale
GM-106A/B
Yard switching
engines
Rail hopper car
Wood chips
Rail spur
to ramp
GY-109
Wood chip
rail car scale
PP-101
Flume pump
GS-101
Wood bucket
conveyor
GM-104 A/B/S
Front end loaders
Wood chip pile
300' x 300' x 60' high
300'
GF-103
Chip pile screen
GS-105
Magnetic chip
cleaner
Wood chip feed
to MB-216
GS-102
Jetbelt conveyor

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-100
Wood Chip Handling, Receiving,
Storage, Feeding

Process Flow Diagram
Figure 100-1

Arthur J. Power and Associates, Inc.
January 26, 1989

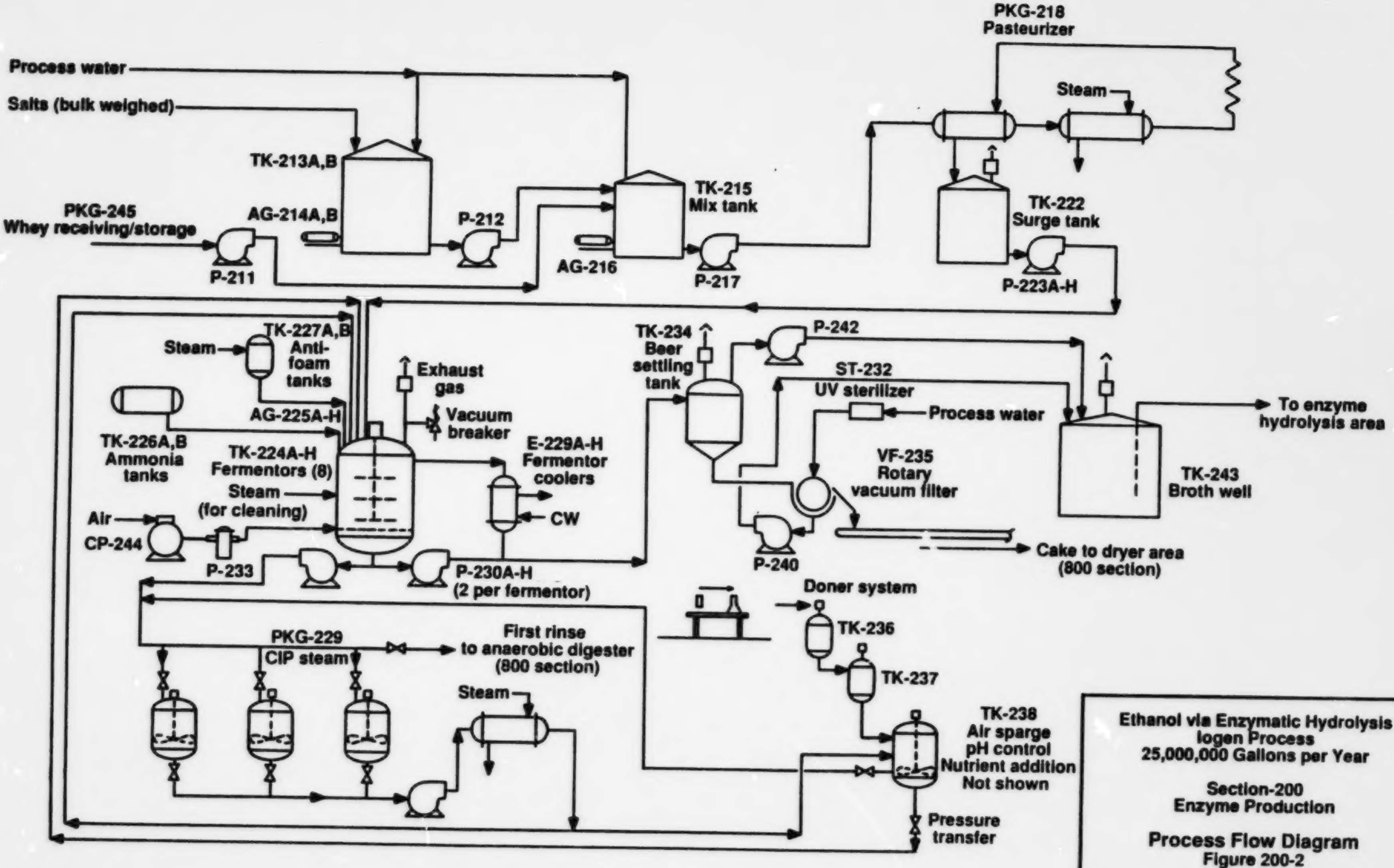

W-201
Vibrating
rotary feeder
Wood chips
from storage
(100 section)
MP steam from
header to W-203A-D
(from 800 section)
Vent
V-203A-D
Steam explosion
guns
(26" x 8'10")
M-201
MP flash
vessel
(12'6" x 29')
M-203A-D
Steam explosion
feed bins
(9'26" x 14'6")
To beer still
(400 section)
R-201
Vacuum
pump
Atmosphere
T-201
CW
CW
P-204AB
Water wash
recycle pumps
Process
water
To hydrolysis
(200 section)
W-202
washer screw
conveyor
W-203
Washed
cellulose
belt conveyor
Beer still
recycle
(dilution)
(400 section)
V-201
Counter current
water/alkali
wash
M-202
Vacuum flash
vessel
(10' x 10')
To anaerobic digestion
(800 section)
P-201A/B
Anaerobic feed
transfer pump
T-201
Vacuum flash
condenser
P-203AB
Water/alkali
wash feed
pumps

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-200
Steam Explosion
Pretreatment

Process Flow Diagram
Figure 200-1

Arthur J. Power and Associates, Inc.
January 26, 1989


PKG-218
Pasteurizer
Process water
Salts (bulk weighed)
Steam
TK-213A,B
TK-215
Mix tank
PKG-245
Whey receiving/storage
AG-214A,B
P-212
TK-222
Surge tank
P-211
AG-216
P-217
P-223A-H
TK-234
Beer
settling
tank
P-242
Steam
TK-227A,B
Anti-
foam
tanks
Exhaust
gas
ST-232
UV sterilizer
Vacuum
breaker
Process water
To enzyme
hydrolysis area
AG-225A-H
TK-226A,B
Ammonia
tanks
TK-224A-H
Fermentors (8)
E-229A-H
Fermentor
coolers
VF-235
Rotary
vacuum filter
TK-243
Broth well
Steam
(for cleaning)
Air
CW
CP-244
Cake to dryer area
(800 section)
P-233
P-230A-H
(2 per fermentor)
P-240
Doner system
TK-236
PKG-229
CIP steam
First rinse
to anaerobic digester
(800 section)
TK-237
Steam
TK-238
Air sparge
pH control
Nutrient addition
Not shown
Pressure
transfer

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-200
Enzyme Production

Process Flow Diagram
Figure 200-2

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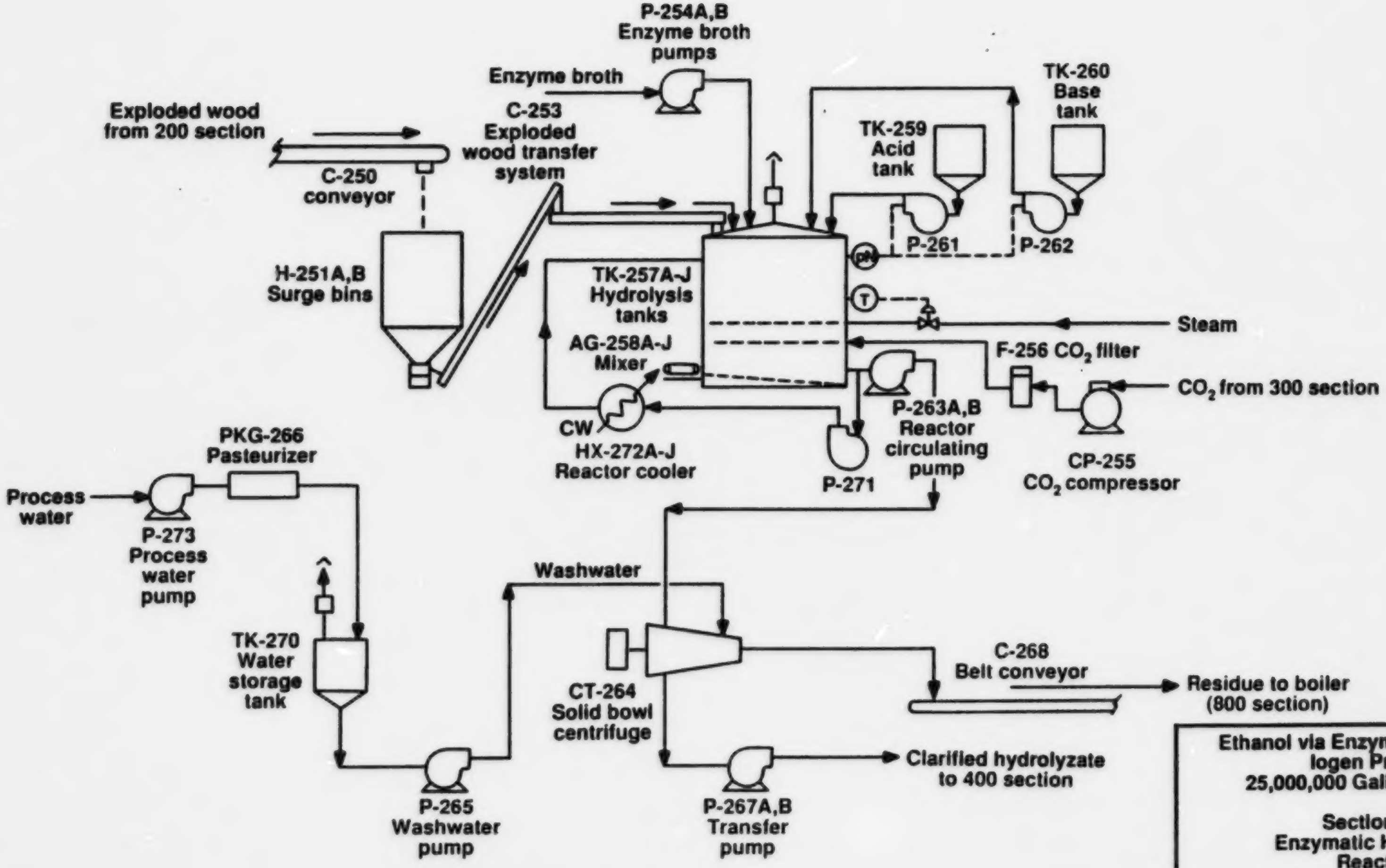
January 26, 1989

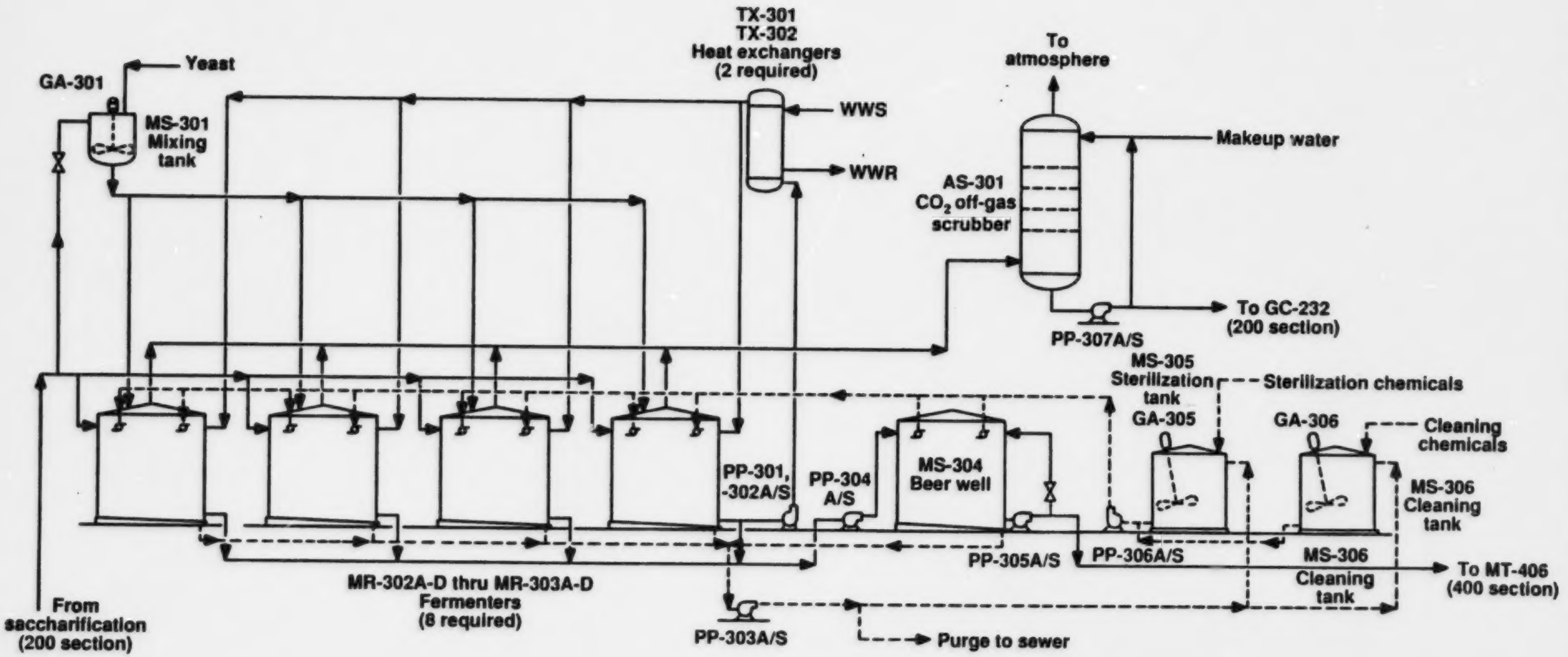

P-254A,B
Enzyme broth
pumps
Enzyme broth
TK-260
Base
tank
Exploded wood
from 200 section
C-253
Exploded
wood transfer
system
TK-259
Acid
tank
C-250
conveyor
P-261
P-262
H-251A,B
Surge bins
TK-257A-J
Hydrolysis
tanks
pH
T
Steam
AG-258A-J
Mixer
F-256 CO₂ filter
CO₂ from 300 section
CW
HX-272A-J
Reactor cooler
P-263A,B
Reactor
circulating
pump
P-271
CP-255
CO₂ compressor
PKG-266
Pasteurizer
Process
water
P-273
Process
water
pump
Washwater
TK-270
Water
storage
tank
C-268
Belt conveyor
Residue to boiler
(800 section)
CT-264
Solid bowl
centrifuge
Clarified hydrolyzate
to 400 section
P-265
Washwater
pump
P-267A,B
Transfer
pump

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-200
Enzymatic Hydrolysis
Reaction

Process Flow Diagram
Figure 200-3

Arthur J. Power and Associates, Inc.
January 26, 1989


GA-301
Yeast
MS-301 Mixing tank
TX-301
TX-302
Heat exchangers (2 required)
WWS
WWR
To atmosphere
Makeup water
AS-301 CO2 off-gas scrubber
To GC-232 (200 section)
PP-307A/S
MS-305 Sterilization tank
Sterilization chemicals
GA-305
GA-306
Cleaning chemicals
PP-301, -302A/S
PP-304 A/S
MS-304 Beer well
MS-306 Cleaning tank
PP-305A/S
PP-306A/S
MS-306 Cleaning tank
To MT-406 (400 section)
From saccharification (200 section)
MR-302A-D thru MR-303A-D Fermenters (8 required)
PP-303A/S
Purge to sewer

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-300
Fermentation

Process Flow Diagram
Figure 300-1

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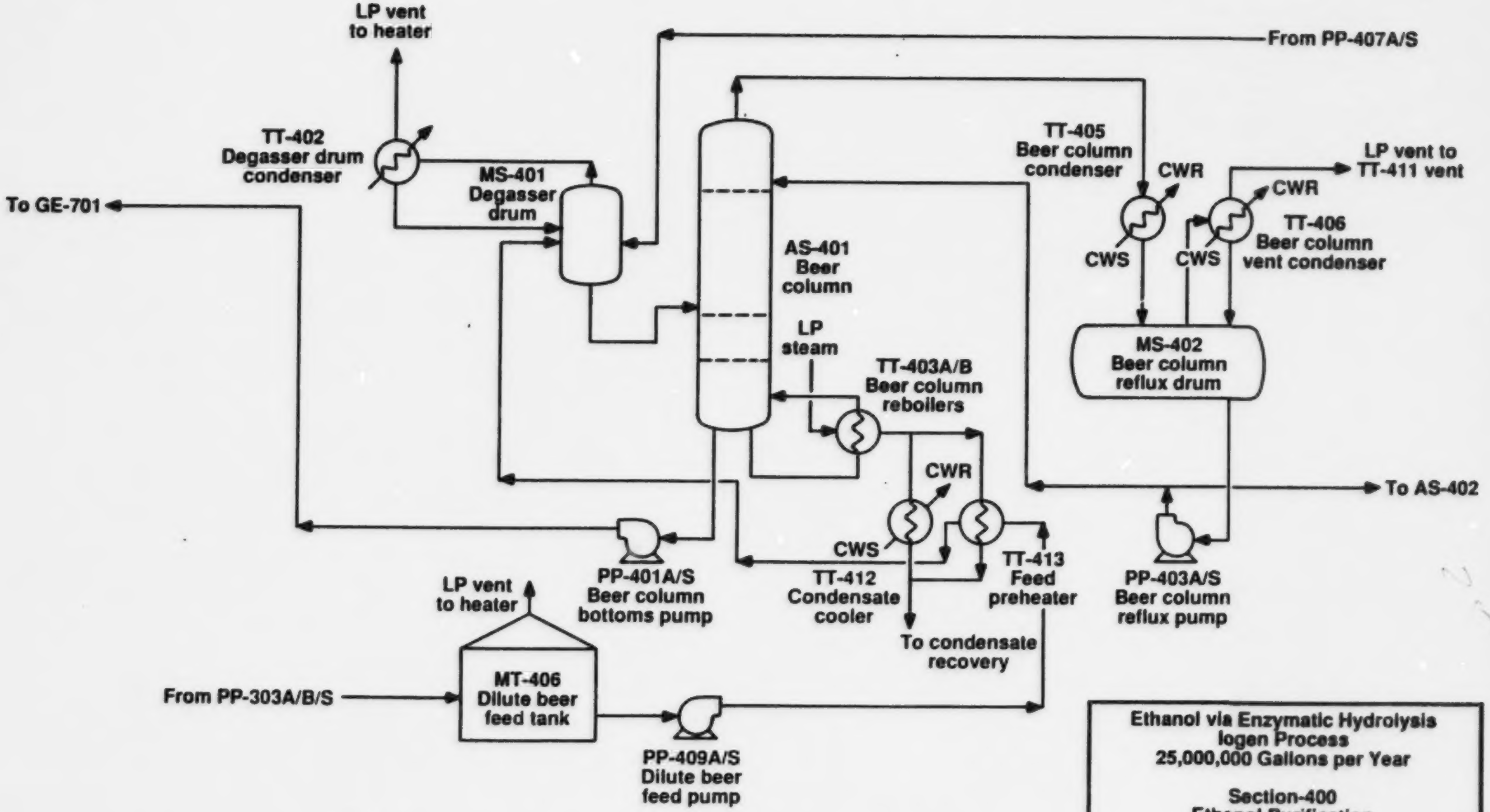
January 26, 1989

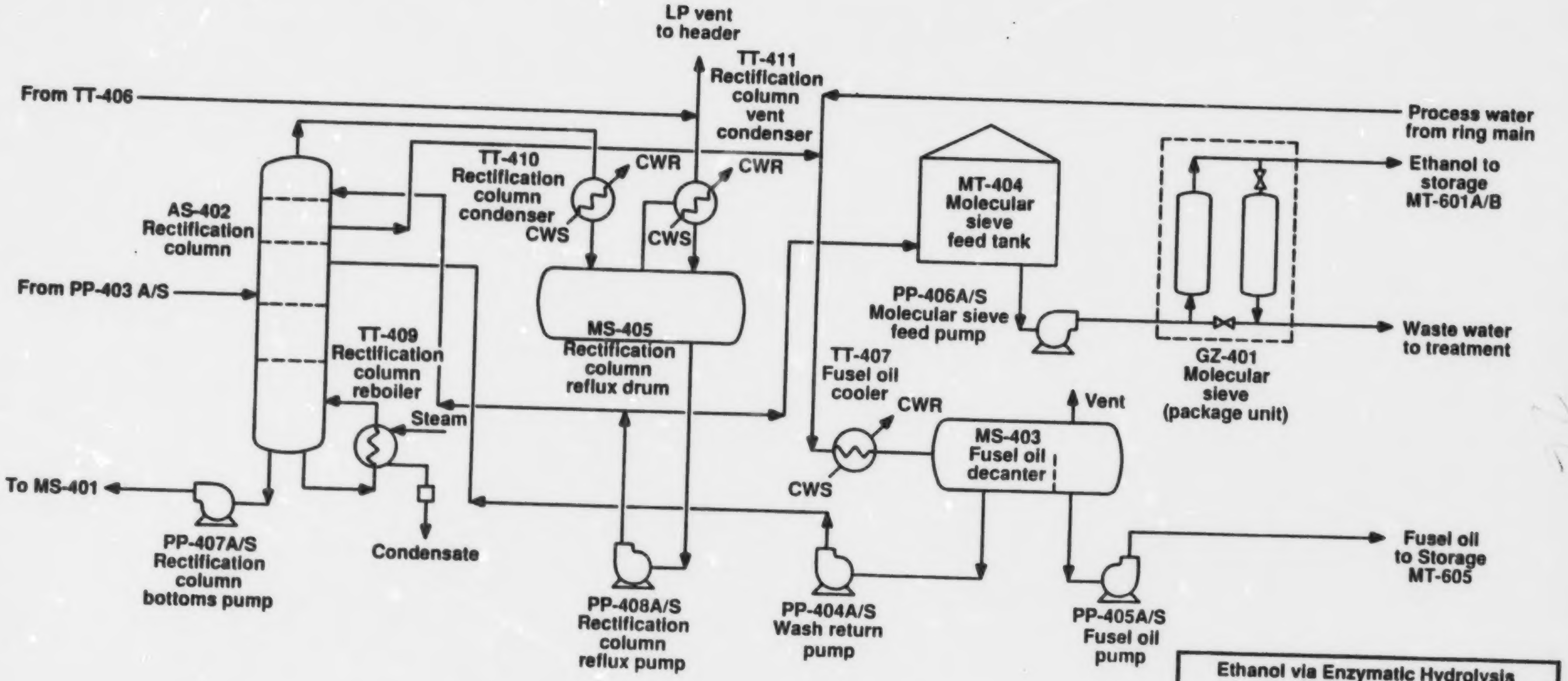

LP vent
to heater
TT-402
Degasser drum
condenser
MS-401
Degasser
drum
To GE-701
From PP-407A/S
AS-401
Beer
column
LP
steam
TT-403A/B
Beer column
reboilers
TT-405
Beer column
condenser
CWR
CWS
CWR
CWS
LP vent to
TT-411 vent
TT-406
Beer column
vent condenser
MS-402
Beer column
reflux drum
To AS-402
CWR
CWS
TT-412
Condensate
cooler
TT-413
Feed
preheater
To condensate
recovery
PP-401A/S
Beer column
bottoms pump
PP-403A/S
Beer column
reflux pump
LP vent
to heater
MT-406
Dilute beer
feed tank
From PP-303A/B/S
PP-409A/S
Dilute beer
feed pump

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-400
Ethanol Purification
(Beer Still)

Process Flow Diagram
Figure 400-1

Arthur J. Power and Associates, Inc.
January 26, 1989


LP vent to header
TT-411 Rectification column vent condenser
From TT-406
Process water from ring main
TT-410 Rectification column condenser
CWR
CWR
CWS
CWS
AS-402 Rectification column
MT-404 Molecular sieve feed tank
Ethanol to storage MT-601A/B
From PP-403 A/S
MS-405 Rectification column reflux drum
PP-406A/S Molecular sieve feed pump
Waste water to treatment
TT-409 Rectification column reboiler
TT-407 Fusel oil cooler
GZ-401 Molecular sieve (package unit)
Steam
CWR
Vent
MS-403 Fusel oil decanter
To MS-401
CWS
Condensate
Fusel oil to Storage MT-605
PP-407A/S Rectification column bottoms pump
PP-408A/S Rectification column reflux pump
PP-404A/S Wash return pump
PP-405A/S Fusel oil pump

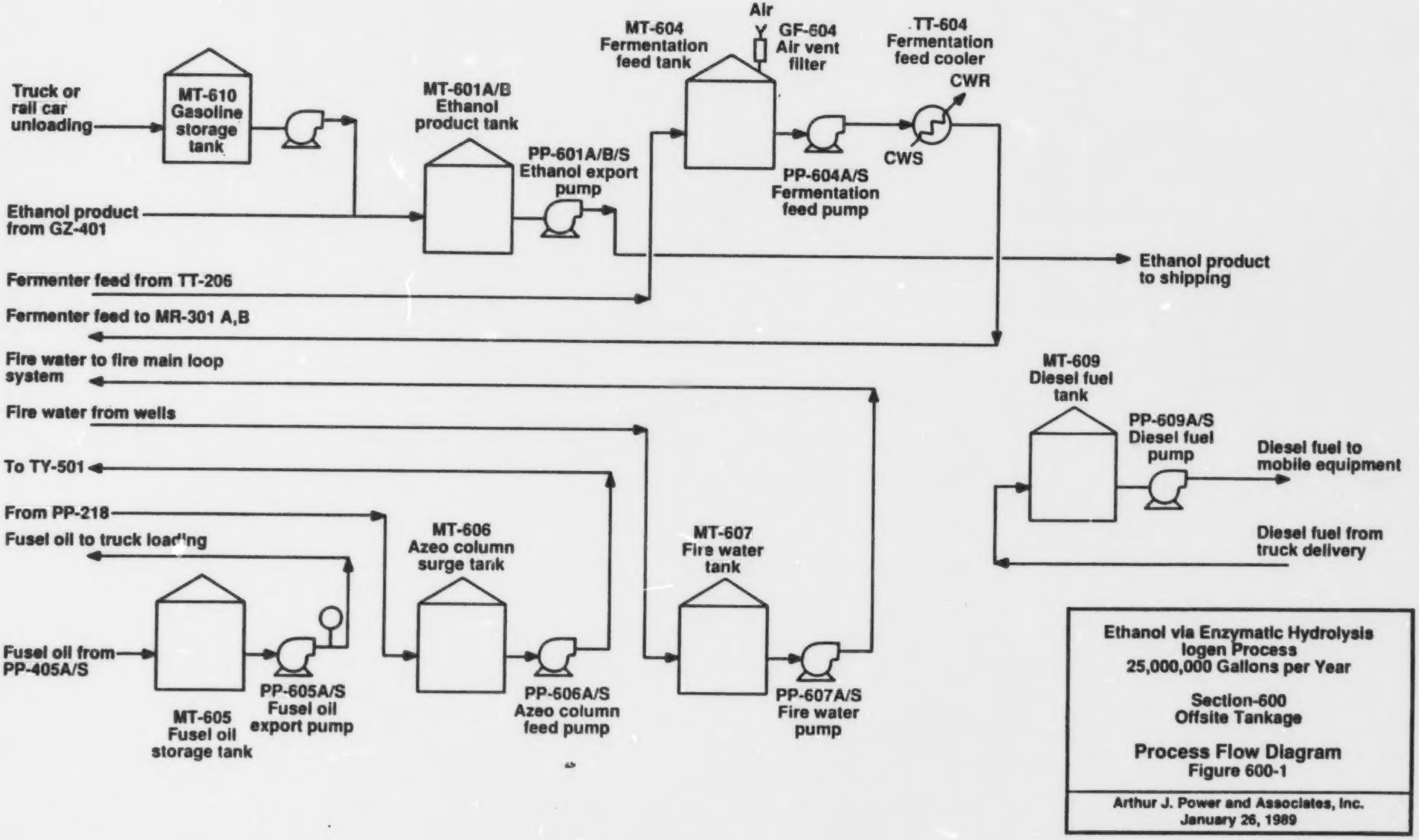
Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-400
Ethanol Purification
(Dehydration)

Process Flow Diagram
Figure 400-2

Arthur J. Power and Associates, Inc.
January 26, 1989

26

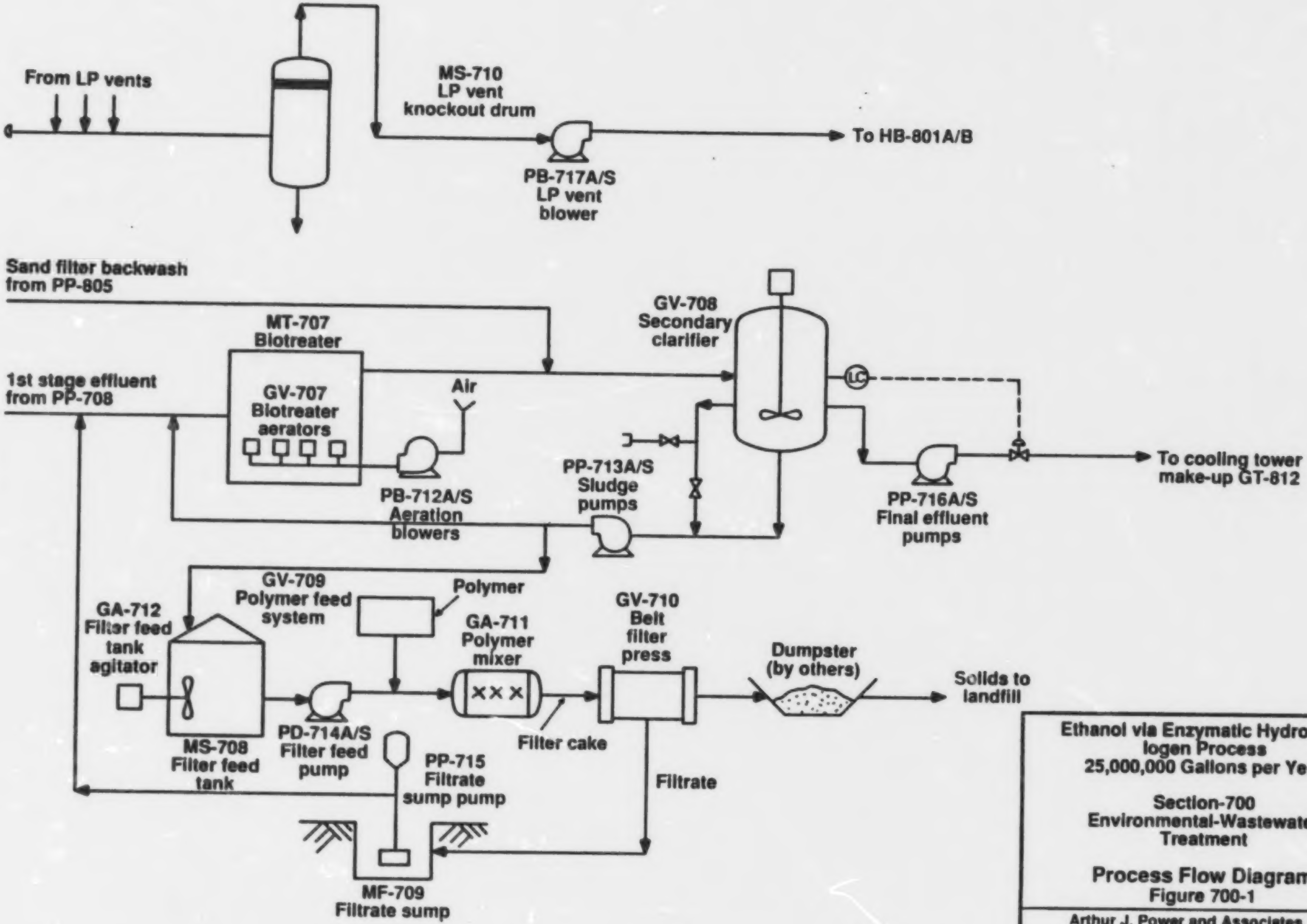

Truck or rail car unloading
MT-610 Gasoline storage tank
MT-601A/B Ethanol product tank
PP-601A/B/S Ethanol export pump
MT-604 Fermentation feed tank
Air
GF-604 Air vent filter
TT-604 Fermentation feed cooler
CWR
CWS
PP-604A/S Fermentation feed pump
Ethanol product from GZ-401
Ethanol product to shipping
Fermenter feed from TT-206
Fermenter feed to MR-301 A,B
Fire water to fire main loop system
Fire water from wells
To TY-501
From PP-218
Fusel oil to truck loading
Fusel oil from PP-405A/S
MT-605 Fusel oil storage tank
PP-605A/S Fusel oil export pump
MT-606 Azeo column surge tank
PP-606A/S Azeo column feed pump
MT-607 Fire water tank
PP-607A/S Fire water pump
MT-609 Diesel fuel tank
PP-609A/S Diesel fuel pump
Diesel fuel to mobile equipment
Diesel fuel from truck delivery

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-600
Offsite Tankage

Process Flow Diagram
Figure 600-1

Arthur J. Power and Associates, Inc.
January 26, 1989

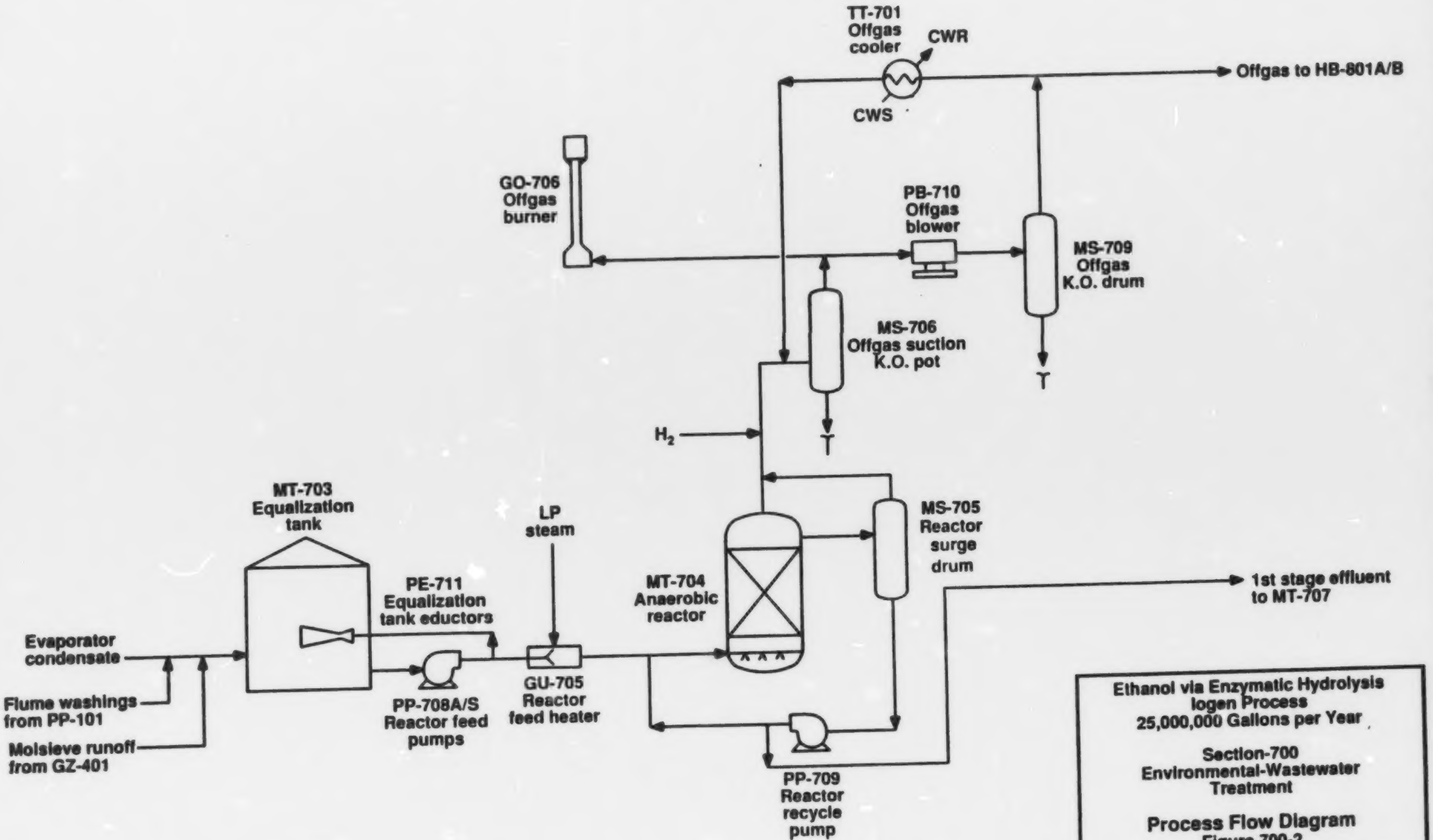

From LP vents
MS-710
LP vent
knockout drum
PB-717A/S
LP vent
blower
To HB-801A/B
Sand filter backwash
from PP-805
1st stage effluent
from PP-708
MT-707
Biotreater
GV-707
Biotreater
aerators
Air
PB-712A/S
Aeration
blowers
GV-708
Secondary
clarifier
LC
PP-713A/S
Sludge
pumps
PP-716A/S
Final effluent
pumps
To cooling tower
make-up GT-812
GV-709
Polymer feed
system
Polymer
GA-712
Filter feed
tank
agitator
MS-708
Filter feed
tank
PD-714A/S
Filter feed
pump
GA-711
Polymer
mixer
Filter cake
GV-710
Belt
filter
press
Dumpster
(by others)
Solids to
landfill
PP-715
Filtrate
sump pump
Filtrate
MF-709
Filtrate sump

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-700
Environmental-Wastewater
Treatment

Process Flow Diagram
Figure 700-1

Arthur J. Power and Associates, Inc.
January 26, 1989

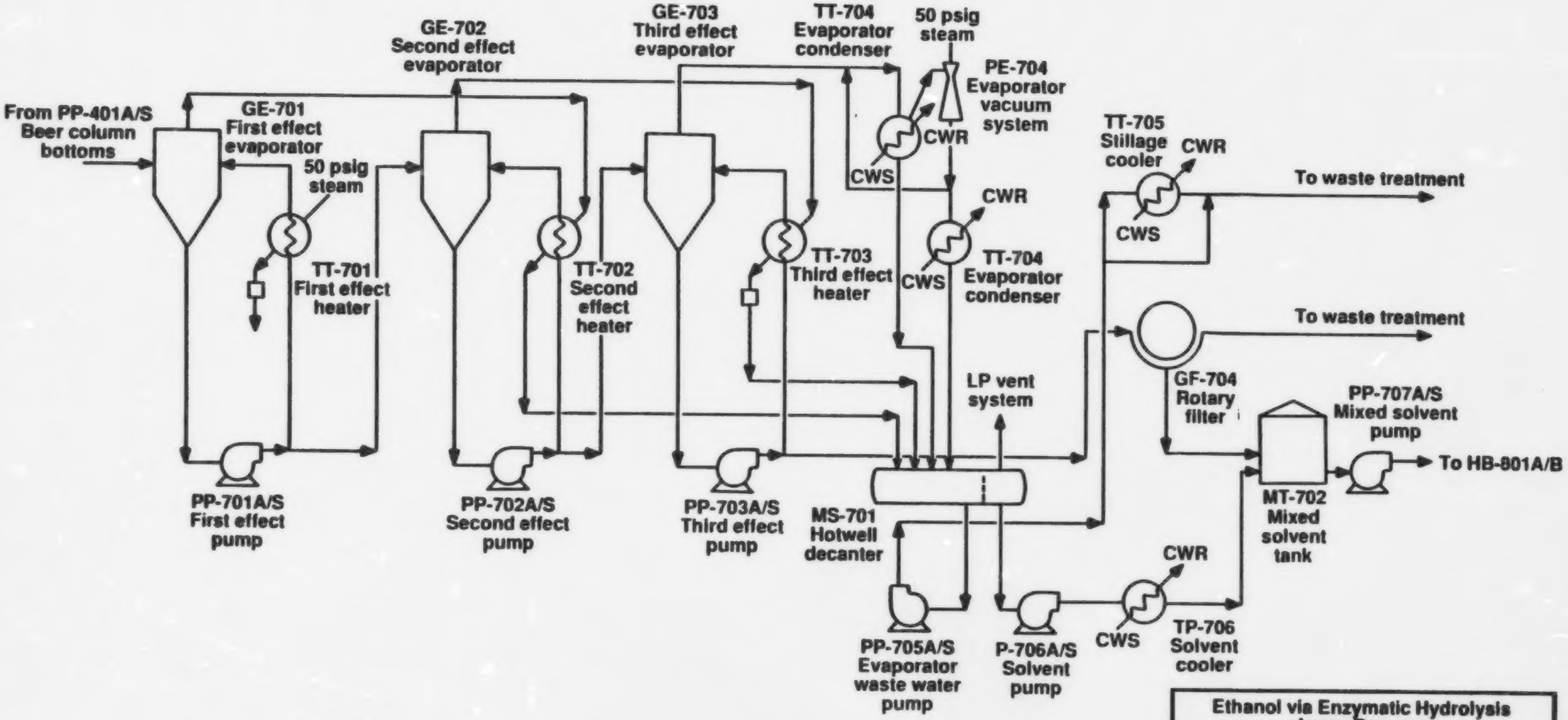

TT-701
Offgas
cooler
CWR
CWS
Offgas to HB-801A/B
GO-706
Offgas
burner
PB-710
Offgas
blower
MS-709
Offgas
K.O. drum
MS-706
Offgas suction
K.O. pot
H_2
MT-703
Equalization
tank
LP
steam
MS-705
Reactor
surge
drum
PE-711
Equalization
tank eductors
MT-704
Anaerobic
reactor
1st stage effluent
to MT-707
Evaporator
condensate
Flume washings
from PP-101
Moisieve runoff
from GZ-401
PP-708A/S
Reactor feed
pumps
GU-705
Reactor
feed heater
PP-709
Reactor
recycle
pump

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-700
Environmental-Wastewater
Treatment

Process Flow Diagram
Figure 700-2

Arthur J. Power and Associates, Inc.
January 26, 1989

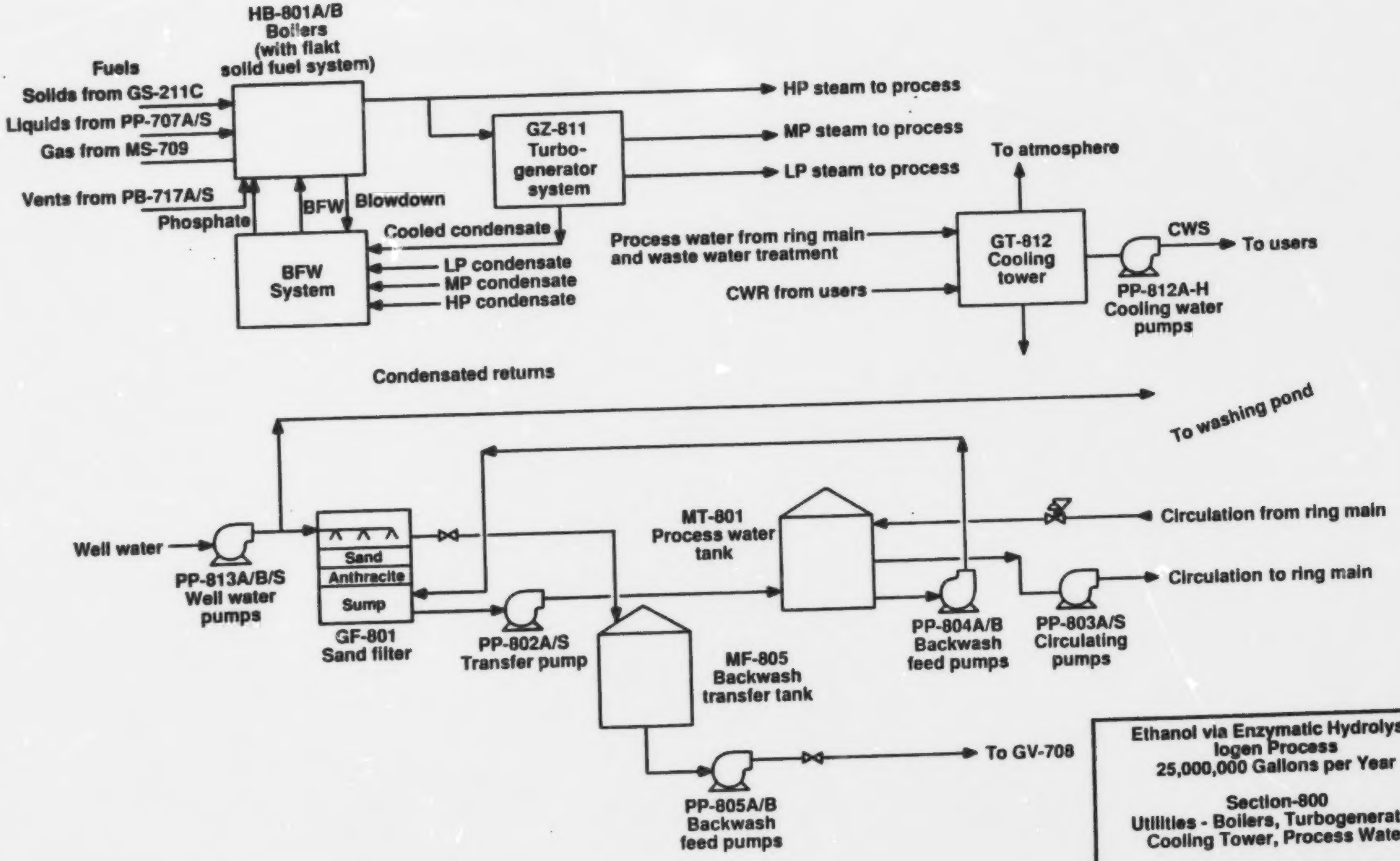

From PP-401A/S Beer column bottoms
GE-701 First effect evaporator
50 psig steam
TT-701 First effect heater
PP-701A/S First effect pump
GE-702 Second effect evaporator
TT-702 Second effect heater
PP-702A/S Second effect pump
GE-703 Third effect evaporator
TT-703 Third effect heater
PP-703A/S Third effect pump
TT-704 Evaporator condenser
50 psig steam
PE-704 Evaporator vacuum system
CWS
CWR
CWR
CWS
TT-704 Evaporator condenser
LP vent system
MS-701 Hotwell decanter
PP-705A/S Evaporator waste water pump
P-706A/S Solvent pump
TT-705 Stillage cooler
CWR
CWS
To waste treatment
GF-704 Rotary filter
To waste treatment
PP-707A/S Mixed solvent pump
To HB-801A/B
MT-702 Mixed solvent tank
CWR
CWS
TP-706 Solvent cooler

Ethanol via Enzymatic Hydrolysis
logen Process
25,000,000 Gallons per Year

Section-700
Environmental-Wastewater
Treatment

Process Flow Diagram
Figure 700-3

Arthur J. Power and Associates, Inc.
January 26, 1989


HB-801A/B
Boilers
(with flakt
solid fuel system)
Fuels
Solids from GS-211C
Liquids from PP-707A/S
Gas from MS-709
Vents from PB-717A/S
Phosphate
BFW
Blowdown
BFW
System
Cooled condensate
LP condensate
MP condensate
HP condensate
GZ-811
Turbo-
generator
system
HP steam to process
MP steam to process
LP steam to process
To atmosphere
Process water from ring main
and waste water treatment
CWR from users
GT-812
Cooling
tower
CWS
To users
PP-812A-H
Cooling water
pumps
Condensated returns
To washing pond
Well water
PP-813A/B/S
Well water
pumps
Sand
Anthracite
Sump
GF-801
Sand filter
PP-802A/S
Transfer pump
MT-801
Process water
tank
MF-805
Backwash
transfer tank
Circulation from ring main
Circulation to ring main
PP-804A/B
Backwash
feed pumps
PP-803A/S
Circulating
pumps
PP-805A/B
Backwash
feed pumps
To GV-708

Ethanol via Enzymatic Hydrolysis
Iogen Process
25,000,000 Gallons per Year

Section-800
Utilities - Boilers, Turbogenerator,
Cooling Tower, Process Water

Process Flow Diagram
Figure 800-1

Arthur J. Power and Associates, Inc.
January 26, 1989

Appendix B. Technology Review

Introduction

The past ten years has witnessed the emergence of biological conversion of wood to ethanol from a laboratory curiosity to a technology nearly ready for commercial development. Significant breakthroughs in pretreatment of lignocellulosic feedstocks and development of superior microorganisms for producing cellulase enzymes have provided the principal thrust for propelling the technology toward commercial reality. Organisms that ferment xylose sugars to ethanol show great promise for adding the commercial potential of these process, as well as, the utilization of the lignin fraction of the feedstock for production of fuels and chemicals. Advances have been made in bioprocessing techniques that offer additional improvements to the economic performance of these systems.

As yet there are no commercial scale facilities on stream to demonstrate the commercial feasibility of these processes. The lack of a commercial facility is, therefore, the principal barrier to commercial exploitation of the technology. A number of engineering and modeling studies have been complete for various conversion processes, however, there remains a high degree of uncertainty in the economic promise of these processes. Part of the uncertainty is predicting the price of energy at some future date and the crossover point for production costs for ethanol and petroleum-based fuels. Scale up factors for moving bench scale and research technology to pilot scale is highly uncertain. Finally, the current level of the technology will not produce ethanol at a price competitive with petroleum-based fuels and the uncertainty of achieving targeted research goals limits commercial adaptation.

Background

The biological processing of woody feedstocks is a complicated undertaking that is controlled by the nature of the feedstock and the chemical attacking agent. In this section the feedstock characteristics will be discussed followed by a general discussion of acid and enzymatic hydrolysis of cellulose.

Cellulose may be converted to ethanol in two discrete steps. The cellulose is hydrolyzed to glucose, which is then fermented to ethanol. Fermentation technology is well developed therefore, most of the recent research activity has centered on developing an economical method for completing the hydrolysis step. Cellulose may be hydrolyzed to glucose chemically with acid or enzymatically.

Acid hydrolysis processes have the disadvantage that they require severe conditions of high temperature and low pH. Such conditions make it necessary to employ expensive corrosion-resistant equipment. Conversion efficiency is limited due to glucose degradation in dilute acid systems. The economic constraints of nearly total acid recycle requirements limit the application of concentrated acid systems. Enzymatic processes have been hampered by the high cost of enzyme production, the limited accessibility of the substrate to the enzyme, and slow reaction rates. However, enzymatic processes are performed at less severe reaction conditions and have the potential, due to the high specificity of enzymatic reactions, for total conversion of cellulose to glucose.

1.1 Feedstock Characteristics

Wood has a complex structure and is composed primarily of three biopolymers cellulose, hemicellulose (the carbohydrates), and lignin. Cellulose is a linear polymer of D-glucose (a six carbon sugar) molecules bonded together by beta-glycosidic linkages. The cellulose fibers are arranged in bundles of parallel chains in which adjacent chains are bound together by hydrogen bonds forming a crystalline matrix with great mechanical strength and high chemical stability. The bonds between the glucose units are the weakest in the structure and provide the area of attack by hydrolytic agents, and subsequent hydrolysis of the cellulose to glucose.

Hemicellulose is a biopolymer consisting of a mixture of five-carbon and six-carbon sugars,. and organic acids. Hardwoods contain mainly the five-carbon sugar, xylose, while softwoods contain mainly the six-carbon sugar mannose. Mannose is readily fermented by standard industrial yeasts, although at a slower rate than glucose, while xylose is not fermentable with these same yeasts. Hemicellulose composition (see table 1) and structure vary greatly between species and unlike cellulose, is amorphous and easily hydrolyzed.

Table 1. The Composition of Various Types of Biomass.

Material	Cellulose	Hemicellulose	Pentose	Lignin	Extractive
Hardwoods	43-45	23-35	12-24	16-24	2-8
Softwoods	41-43	24-33	8-14	24-33	1-7
Grasses	25-40	25-50	25-29	10-30	---
Corn Cobs	41	36	30-36	6	14

Lignin is a phenolic polymer and is the principal non-carbohydrate portion of the cell wall. Lignin is mixed with and chemically bonded to the hemicellulose and surrounds the cell wall to provide a substantial barrier to chemical and physical attack on the microfibrils of cellulose.

The properties of the feedstock play an important role in determining the rate of hydrolysis, what type of pretreatment is required, and to what extent xylose fermentation aids the economic performance of a process. The output quality of the lignin is, to some extent, determined by the choice of feedstock. The amount and structure of the lignin vary among the various feed materials. Therefore, it is important to account for the feedstock properties in any analysis of a wood to ethanol process.

1.2 Acid Hydrolysis of Cellulose

Acid hydrolysis of lignocellulosic biomass requires a minimum of pretreatment, generally some sort of size reduction to provide standard chips or some smaller particle size. The small size of the acid molecule in solution permits easy penetration of the wood structure and attack of the glycosidic linkages.

A brief description of the mechanism of acid catalyzed hydrolysis of cellulose to glucose follows: The rate limiting step is the flexure of the glucose molecule from a chair confirmation to a semiplanar configuration. In crystalline cellulose the glucose molecules are rigidly held in packed arrays. This crystal structure inhibits the flexure of the glucose and contributes to the slow hydrolysis rate. Amorphous cellulose and the open structured hemicellulose have very high hydrolysis rates in the absence of the restrictions to ring flexure. It must be stressed that the acid molecule is a catalyst for this reaction and initiates the flexure process. Once the glucosidic molecule is in the semiplanar conformation, a methyl group is released followed by the quick addition of a water molecule. This water addition completes the formation of glucose and releases the acid species back into solution for attack on another glucosidic molecule.

One method for breaking down crystalline cellulose is with high temperature dilute sulfuric acid. Unfortunately, conditions sufficient to solubilize the sugars are also strong enough to degrade the product sugars. Therefore, sugar degradation is a key problem in dilute acid hydrolysis. The general reaction paths for acid hydrolysis are shown in table 2.

Table 2. The Principal Acid Hydrolysis Reactions.

1. Crystalline cellulose ---> Glucose ---> HMF --------> Tars
2. Amorphous Cellulose ---> Glucose ---> HMF --------> Tars
3. Amorphous Xylans ---> Xylose--->Furfural------> Tars

The rate of hydrolysis is very high for the amorphous fractions, while the crystalline cellulose has a slow rate. Once the sugars are in solution the subsequent reactions proceed at relatively high rates.

1.3 Acid Hydrolysis Processes

There are numerous processes and methods for using acid to hydrolyze lignocellulosic feedstocks. For this review these various approaches will be separated into two broad types of processes: dilute acid processes and concentrated acid processes. Acid hydrolysis processes have been around for over fifty years and some processes have been operated on a commercial scale in Germany and Russia. Dilute acid processes generally suffer from problems associated with low yield and degradation products in the sugar solution. Concentrated acid processes, whether liquid or gaseous types, require high acid recycle for economic feasibility.

1.3.1 Dilute Acid Processes

Figures b1 and b2 show the consequences of varying the temperature from 180°C to 265°C, using 1 per cent sulfuric acid, on the hydrolysis of cellulose and xylan in poplar wood. Figure b1 shows that after two minutes at 180 degrees about 80% of the xylan is converted to xylose and the yield is starting to reduce, indicating the production of some degradations products.

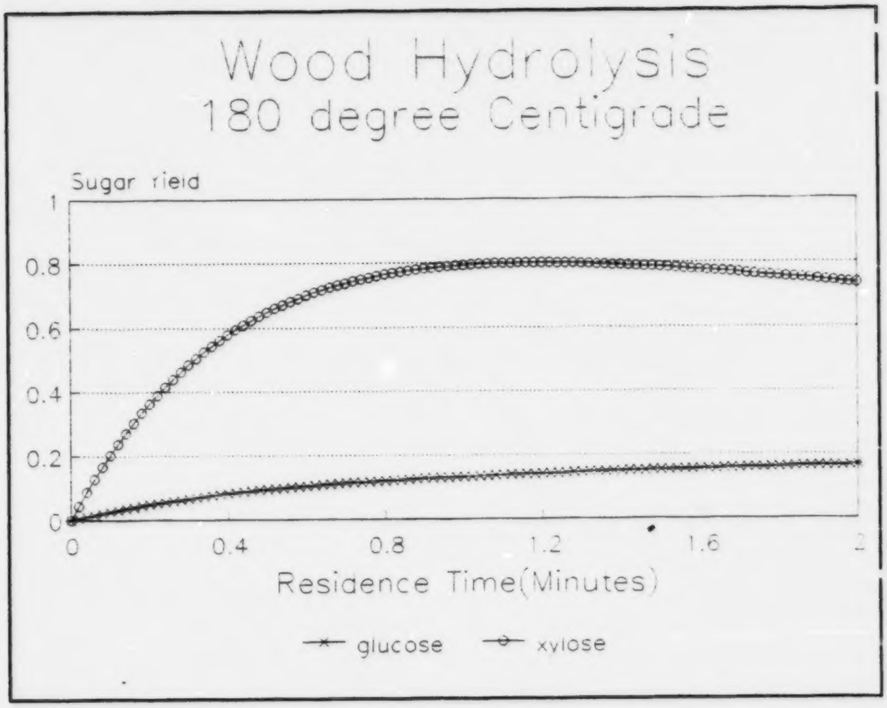


Figure b1. Low Temperature Acid Hydrolysis

The cellulose fraction, during the same two minutes, shows less than 20% conversion. This figure illustrates the real weakness of mild temperature dilute acid hydrolysis, i.e., high conversion yield for cellulose require long times or large volumes of acid. Long liquid residence times increase the productions of degradations products and large liquid volumes produce a highly dilute, uneconomic sugar stream.

If the temperature is reduced to 150°C about 85% of the hemicellulose is removed in five minutes and the cellulose is left relatively untouched. This may be a good pretreatment or part of a two stage hydrolysis process, but the economic feasibility is questionable.

Figure 2 shows that at 265°C and 1% acid, the glucose yield is about 70% in 4-5 seconds and the xylose yield is 85% in about 1-2 seconds.

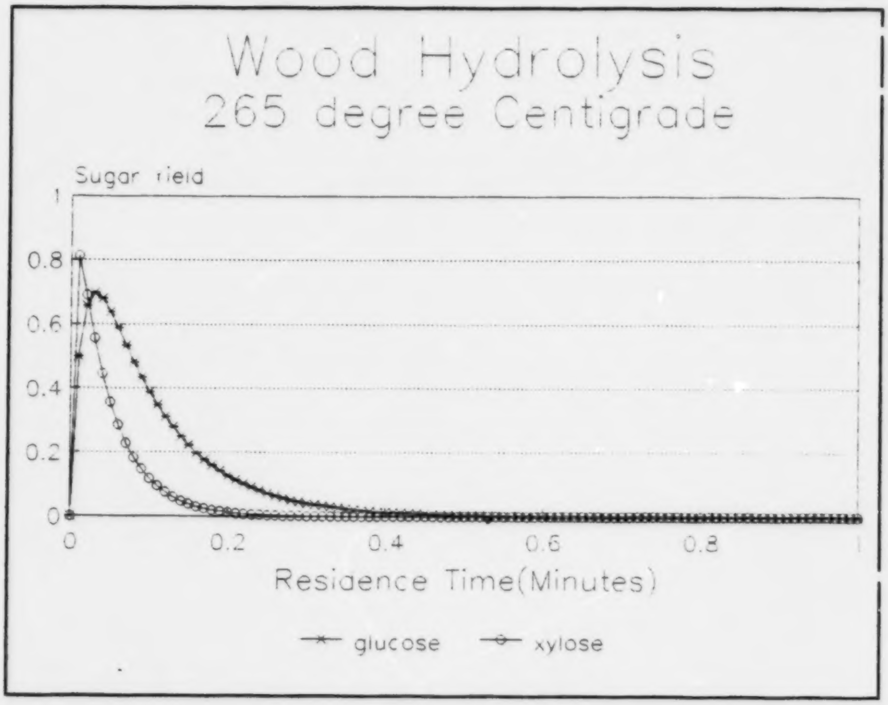


Figure b2. High Temperature Acid Hydrolysis

The xylose sugars are degraded totally by the end of twelve seconds and the glucose is totally degraded after about 24 seconds. This figure shows that high yields are possible in short residence time dilute acid hydrolysis processes and illustrates the difficulty to be expected in constructing a practical system to carry out the process.

The problem of getting xylose out of the reactor before it is completely degraded would be difficult and designing a system for loading wood chips into a reactor, heating to 265°C, and quenching the reaction products in 4-5 seconds is a formidable engineering problem. The short residence time dilute acid process can be modified by increasing the acid concentration and reducing the temperature, however, the optimum results still produce the same type of problem seen above.

1.3.2 Concentrated Acid Processes

Concentrated acids functions by breaking down the crystalline structure of cellulose and produce an amorphous cellulose that is easy to hydrolyze. These systems produce clean sugars and almost quantitative yields at very moderate temperatures.

The only barrier to implementation of this technical approach on a commercial scale is the necessity to recycle the acid in the process. In the case of sulfuric acid, a process is required that can recycle the acid cheaper than the purchase price of fresh acid. At present there is no such process. With hydrochloric and hydrofluoric acid the same constraint applies, but with more severe restrictions on the recycle because of the higher initial costs of these acids. This is both a technical and engineering problem and by no means trivial.

1.4 Enzymatic Hydrolysis of Cellulose

Enzymatic hydrolysis of cellulose to glucose is performed by a class of enzymes called cellulases. Cellulase enzymes are a complex group of enzymes, each of which plays a particulars catalytic role in the depolymerization of cellulose to glucose monomer units.

The sources of cellulase enzymes include anaerobic protozoa, aerobic fungi, and aerobic and anaerobic bacteria. The most extensively studied cellulase enzyme have been produced from aerobic, mesophilic fungi, and of these, most researchers have focused on strains of Trichoderma reesei. These organisms are of interest because they secrete all the enzyme components necessary to hydrolyze cellulose; the cellulase produced is resistant to chemical inhibitors and is stable at temperatures of 50°C for up to 48 hours.

The cellulase complex consists of as many as eleven different enzymes, However, the activity has been shown consist of three main types of enzymes: Beta-1,4-glucan glucanohydrolase, an endoenzyme; Beta-1,4-glucan cellobiohydrolase, an exo-enzyme; and Beta-glucosidase. The action of this group of enzyme is very complex with the exo and endo enzymes thought to act together on the surface of the cellulose and Beta-glucosidase acting on the soluble fractions split off by the surface enzymes. End-product inhibition limits reaction rates and extent. Glucose has been shown to inhibit Beta-glucosidase, and cellobiose has been shown to inhibit the cellobiohydrolase enzyme. As the concentration of these sugars increase in the reaction media the activity of the enzymes is reduced and can be totally stopped. A great deal of the research effort in enzymatic process technology is directed to reducing these effects.

1.5 Enzymatic Hydrolysis Processes

Many different flowsheets have been proposed for enzymatic cellulose-to-ethanol processes and all fall into one of three categories: (a) separate hydrolysis, fermentation, and enzyme production steps (SHF), (B) simultaneous saccharification and fermentation (SSF), which combines the hydrolysis and fermentation reactions in one step; and (c) direct microbial conversion (DMC), which combines all three steps of enzyme production, hydrolysis, and fermentation. The positive and negative attributes of each of these type of processes is discussed in the following sections.

1.5.1 Separate Hydrolysis and Fermentation (SHF)

The first enzymatic hydrolysis processes is called the separate hydrolysis and fermentation process. As the name implies, hydrolysis of cellulose to glucose an fermentation of the glucose to ethanol are carried out as separate operations. The U.S. Army Natick Research and Development Command, the University of California (Department of Chemical Engineering and Lawrence Berkeley Laboratory), and the Indian Institute of Technology that have developed such enzymatic hydrolysis processes. A review of these is provided by Wilke (1980).

The separate hydrolysis and fermentation (SHF) process is the most studied of the three and is therefore the closest to commercialization. Although this process has the most processing steps, more data are available on them because the operations of enzyme production, cellulose hydrolysis, and fermentation can be studied independently. Process economics can be evaluated using standard industrial fermentation and distillation designs. The concept of separate glucose hydrolysis has generated interest perhaps due to the potential production of pharmaceuticals rather than ethanol from the glucose.

A major advantage of SHF is that it can be carried out at the most optimal conditions since each major operation is performed individually. Enzyme production is performed under conditions that produce the best combination of enzyme synthesis and organism growth, within economic constraints on nutrient requirements. Cellulose hydrolysis is performed at the most optimal pH and temperature (45° - 55°C for the Trichoderma reesei enzyme preparation).

Fermentation is performed also at the most optimal conditions of pH and temperature (30°C for many industrial yeast strains). A disadvantage of SHF is the number of individual operations involved. The greater number of processing steps potentially requires a greater capital investment and labor cost. The need to convey materials through several process sections adds to the difficulty of materials handling and maintenance of aseptic conditions. Separate formation of glucose during hydrolysis and subsequent conversion to ethanol allow glucose inhibition of the cellulase enzymes to become a factor in performance.

1.5.2 Simultaneous Saccharification and Fermentation (SSF)

The second enzymatic hydrolysis process is called simultaneous saccharification and fermentation (SSF) because the hydrolysis of cellulose to glucose and the conversion of glucose to ethanol are performed simultaneously. In its simplest form, this process consists of introducing a fermentative organism to the vessel that contains the cellulose and cellulase enzymes.

The SSF process has several advantages. Combining two major processing steps into one reduces the total amount of required materials handling. The fewer times the substrates need to be transferred between processing steps, the easier it is to maintain asepsis. The SSF process itself may promote aseptic conditions during the cellulose hydrolysis because ethanol and anaerobic conditions are present. Labor and capital equipment costs are reduced in the SSF process because of greater process simplicity.

The main advantage of SSF over separate hydrolysis and fermentation may prove to be simultaneous conversion of product sugars to ethanol. Otherwise, these sugars inhibit the growth of cellulase enzymes. Many studies on cellulase enzyme kinetics have indicated that cellobiose, and to a lesser extent glucose, inhibit the hydrolysis of cellulose (Howell and Stuck 1975; Ghose and Des 1971; Huang 1975; Okasaki and Moo-Young 1978; Fan and Lee 1983).

Glucose appears to inhibit the enzyme that converts cellobiose to glucose, allowing the buildup of cellobiose, which in turn inhibits the degradation of cellulose. Some controversy exists as to the amount of the B-glucosidase enzyme (which catalyzes the conversion of cellobiose to glucose) present in the newer strains of the Trichoderma reesei enzyme and the need for supplementation of this enzyme from another source. Removal of glucose during SSF would be possible with levels of this enzyme. Current research indicates that the traditional industrial fermentative organisms (e.g., Saccharomyces cerevisiae, Saccharomyces carlsbergensis, and Candida brassicae), which cannot ferment cellobiose, may be replaced with organisms such as Candida lusitaniae, which can eliminate the need for a B-glucosidase enzyme component.

As an example of the potential enhancement of hydrolysis during SSF due to sugar inhibition removal, one study showed an increase in cellulose conversion from 25% to 40% for 24 and 48 hours of hydrolysis, respectively, compared to simple saccharification (Wilke 1980). Hydrolysis studies at University of California at Berkeley indicate that as much as 10 wt % glucose can be produced in a 48-hour hydrolysis of steam-exploded biomass with a cellulose conversion of 80% regardless of the potential inhibition problems. However, this same conversion might be achieved in less time in an SSF process, or at a lower enzyme-to-cellulose ratio, or at an increased solids loading to produce a higher concentration of product.

A potential problem with SSF processes is the difference in optimal operating conditions for the hydrolysis and fermentation reactions. The cellulase enzymes operate optimally between 45 and 50 degrees C. However, the optimum temperature for most yeast is between 25°C and 35°C. One study showed a decrease in saccharification for the enzyme from the Rut-C30 strain and the E58 strain of the Trichoderma reesei organism of 15% and 27%, respectively, at 28°C, compared to saccharification 50°C (Saddler et Al. 1982).

Since the saccharification of cellulose is the rate limiting step in the process, an operating temperature close to the hydrolysis optimum is desired. Since the rate of fermentation is rapid by comparison, SSF can take place at conditions sub-optimal to fermentation (i.e., at a higher temperature). However, the viability of the fermentative organism must be maintained, and, therefore, a compromise temperature must be chosen.

One study indicated a loss in viability of Saccharomyces cerevisiae at 40°C during SSF, but not for select strains of the Candida brassicae or Saccharomyces carlsbergensis (Takagi 1977). Future research may circumvent the problem of operating conditions by adapting the fermenting organism.

1.5.3 Direct Microbial Conversion (DMC)

The third enzymatic hydrolysis process is called direct microbial conversion. This process requires one less step than the SSF process because enzyme production facilities are not required. The organism, or organisms in the case of a co-culture, are capable of both hydrolyzing cellulose and fermenting the sugar to ethanol.

MIT and General Electric Corporate Research and Development have both developed processes that use a mixed culture of Clostridium thermocellum and Clostridium thermosaccharolyticum (Wilke 1980). Clostridium thermocellum is effective at hydrolyzing both cellulose to glucose and hemicellulose to xylose, but it does not use the xylose. Clostridium thermosaccharolyticum in environmentally and biologically compatible with Clostridium thermocellum an can ferment the xylose to ethanol. Another is Fusarium oxysporum, which can ferment both pentoses and hexoses and hydrolyze cellulose and hemicellulose (Antonopoulos 1979). Both Clostridium thermocellum and Clostridium thermosaccharolyticum are thermophiles and strict anaerobes.

Their anaerobic nature aids process asepsis and avoids the limitations caused by oxygen transfer rates that exist during aerobic fermentation of Trichoderma reesei during cellulase production. Their thermophilic nature allows operation at an elevated temperature (60°C), which aids the process by increased cell growth rates, prevention of viral and bacterial pathogens, and faster rates of solid/liquid separation. Since these organisms are bacterial species, they grow faster than the fungal and yeast species used in the other two processes.

Operation at the higher temperature of 60°C will aid the ethanol purification step. For example, vacuum and flash fermentation techniques for continuous ethanol removal during fermentation are more cost-effective in a process run at higher temperatures. At the lower temperatures of conventional fermentations these techniques suffer from the high costs of vacuum compression, which is required for lower operating pressures.

One of the main advantages of direct microbial conversion is its simplicity; enzyme production, hydrolysis, and fermentation are combined into one step. Also, equipment, materials handling, and labor costs are reduced. Another major advantage is that the feedstock can be used more completely since both the five- and six-carbon sugars are converted to ethanol. As with the other two processes, the direct conversion process economics have suffered from long hydrolysis time, low conversions of cellulose, and low ethanol tolerance of the organisms. In addition, because of the co-production of other fermentative products (mainly acetic acid and lactate), the yields of ethanol per sugar unit have been low.

2 Engineering Feasibility Studies

In 1984 and 1985 the Solar Energy Research Institute solicited private sector engineering companies to bid for contracts to establishing commercial readiness of lignocellulose to ethanol process technology. As a result of this solicitation, five engineering feasibility studies were commissioned. Two for evaluating acid hydrolysis processes and three for evaluating enzymatic hydrolysis processes. These studies were to be site specific, feedstock specific, and technology specific. The result of these studies was an assessment of the current economic potential of each process and recommendations for improvements to enhance the economic feasibility.

2.1 Dilute Acid Hydrolysis

The acid hydrolysis contracts were issued to Badger Engineers, Inc of Cambridge, Mass., And Stone and Webster Engineering Corp. of Boston, Mass. Both firms selected the Dartmouth College high temperature, dilute acid, plug-flow reactor process as their design basis.

2.1.1 Badger Engineering

The Badger study was by far the most comprehensive in scope and detail. The product document is close to an engineering bid package in detail. The design basis is a 5 and 25 million gallons per year plant capacity. The feedstock is hardwood chip delivered to an undefined midwest location. Furfural is the principal byproduct. Lignin and C5 sugars are assumed in the base case to be used as fuel for internal power generation.

Excess electricity is assumed sold to the local power grid.

The economic analysis indicates that long-term success of a venture based on this process is feasible, but depends heavily of the of furfural. Furfural is sold as chemical or as a feed for upgrading to other chemicals, such as, butanol, adipic acid, and maleic anhydride. The base case selling price for ethanol for the 5 million gallon per year case was \$2.83 per gallon and for the 25 million gallon per year case was \$1.80 per gallon. These values for ethanol selling price depend heavily on furfural coproduct credit and selling excess power to the local power grid. With these component removed the ethanol price is in line with the values reported by Stone and Webster.

The Badger study includes an evaluation of the technical risk involved in commercialization of the process based on the present level of development. The risk is analyzed and quantified, and possible process development strategies assessed by a methodology developed by the Rand Corporation. Recommendations for future development are base on the results of the Rand method.

Eight areas of technical risk were identified in the study all associated with the operation of the hydrolysis reactor. The staff at Badger felt that the hydrolysis unit was the only area of major technical risk, since the other operating units are based on existing commercial technology. The eight areas are:

1. Reactor Stability
2. High Consistency Slurry Handling
3. Reactor Feed particle Size
4. Fermentable Sugar and Furfural Yield
5. Hydrolyzate Fermentability
6. Ethanol Product Contaminants
7. Lignin Separability and Washability
8. Stability of Hydrolyzate Sugars

Quantitative measurements of these risk areas was performed either in bench scale tests or at vendor sites, the results were used to complete the Rand analysis. The best case scenario of high coproduct price and optimum performance of the hydrolysis reactor predicted an ethanol selling price of $0.90 per gallon at 15% DCFIROR.

2.1.2 Stone and Webster

The design basis for the study is a 15 million gallon per year of ethanol with eucalyptus trees as the feedstock. The plant was sited in Hawaii and would supply ethanol to the local gasohol market.

The base case design is centered around four hydrolysis reactors in parallel based on the Dartmouth design. Wood chips are fed from a storage pile to a defibration (steam explosion) system which utilizes integrated process steam to soften the chips and provide mechanical shredding to produce a chemical grade pulp. The pulp is washed in a pressurized rotary filter to remove the extractibles and about 50% of the hemicellulose (C5 sugars). This pretreatment approach, using whole chips as the feed, is quite different from the size reduction (grinding) approach used be Badger.

Acid hydrolysis of wood to ethanol is found to be technically feasible. However, significant byproduct credits are necessary for economic feasibility. The base case system produced ethanol with a required selling price of $3.30 per gallon. This value is with no coproduct credits. R and D recommendations include: (1) pentose fermentation to ethanol, (2) production and utilization of lignin derivatives, (3) increase reactor yields, and (4) increase the solids concentration in the reactor.

Several trade-off studies were run and indicated that recovery of C5 sugars derivatives is the most significant ethanol cost reducer. Production of furfural, valued at $0.20 per pound, from xylose could reduce the ethanol selling price by $0.70 per gallon. Production of additional ethanol via C5 fermentation could reduce the ethanol price by $0.60 per gallon. No specific impact is stated for lignin derivatives as a coproduct. Increasing the solids in the reactor from 15% to 23% reduced the ethanol cost by $0.13 per gallon. The optimistic case indicated that a selling price of ethanol as low as $1.70 per gallon could be obtained.

2.2 Enzymatic Hydrolysis Processes

The enzymatic hydrolysis contracts were issued to Chem Systems, Inc. of Terrytown, New York, A.D. Little, Inc. of Cambridge, Mass., And Stone and Webster Engineering Corp. of Boston, Mass. Chem Systems used a dilute acid pretreatment system designed after the Dartmouth plug-flow reactor but operated under much milder conditions. A.D. Little and Stone and Webster used steam explosion as their pretreatment and based the design on data from Iotech in Canada. The A.D. Little study was co-funded with New York State Energy Research and Development Authority(NYSERDA).

2.2.1 Chem Systems

The Chem System study is based on a 25 million gallon per year plant located on Michigan's Northern lower peninsula. The feedstock is a mixture of 80% aspen and the balance mixed hardwoods, mainly maple and birch. The design basis is an enzymatic hydrolysis process of the SHF type using a dilute acid pretreatment based on the Dartmouth plug-flow reactor. The process uses pretreated wood as the carbon source for enzyme production. The plant is set-up to recover carbon dioxide as a co-product and convert the C5 sugars(xylose) to furfural.

The capital cost of the facility was estimated at $120 million. The base case economic performance of the plant shows a net cost of production of ethanol of $1.57 with byproduct credits of $0.62. For a 10% DCF return, the required selling price of ethanol is $2.06 with the byproduct credits and about $2.76 per gallon without the credits. sensitivity studies showed that increasing the solids loading in the hydrolysis reactor to 15% reduced the selling price by $0.27 per gallon and increasing the enzyme productivity by 100% reduced the selling price by $0.17 per gallon. A combination of these two effect and some modest optimization of the pretreatment and hydrolyse section could easily reduce the selling price into the $1.30 to $1.50 per gallon range.

Chem System feels that this enzyme hydrolysis based process is feasible both on technical and economic grounds. Research to optimize the enzyme production and hydrolysis sections of the plant is still required and then the front half of the process must be demonstrated in industrial-type equipment to complete the proof of concept.

2.2.2 A.D. Little

The A.D. Little study is the most detailed of the enzymatic hydrolysis studies and reports the highest value for required selling price for the product ethanol. Two factor contribute to the high estimated value for ethanol in this study; (1) the authors have better knowledge of the biological processes than the staff members at the other engineering firms and (2) the scale of 5.5 million gallons per year is the smallest of the three studied and contributes to the higher ethanol production cost by adding about $2.40 per gallon for capital related charges.

The base case required selling price for ethanol is $3.87 per gallon with byproduct credits for cogenerated electricity and a protein-rich animal feed. Removal of these by-product credits increase the base case price to $5.06 per gallon.

The feasibility study included a plant location in Jefferson County, New York, and the use of deproteinated cheese whey as the substrate for enzyme production. Debarked northern hardwoods were selected as the feedstock for the enzyme hydrolysis operation. Steam explosion was selected as the pretreatment. Total capital investment for the facility was estimated to be $60.58 million in 1984.

The sensitivity analysis showed that increasing hydrolysis yield and high selling price for the lignin residue have the most significant impact on the ethanol selling price. in addition, increasing the rate of enzyme production will reduce the ethanol selling price. The study has excellent details on marketing of by-product and analyses of market penetration requirements for the study region.

The conclusion of the study was that enzyme hydrolysis of wood is not presently economic. Further research and development are also needed to resolve remaining technological uncertainty and to establish markets for new products.

2.2.3 Stone and Webster

The Stone and Webster study is sited on the island of Hawaii, near the city of Hilo. The design basis of the plant is to use enzyme hydrolysis technology to convert eucalyptus wood chips into fuel grade ethanol. The capacity of the plant will be 15 million gallon per year. The process will use sulfuric acid impregnated chips and steam explosion as the pretreatment. Pretreated wood will be the feed for enzyme production.

The capital cost for the facility was estimated at $150 million and the base case design produced ethanol with a required selling price of $3.50 per gallon. Trade-off studies were conducted and found to reduce the selling price of ethanol under the following scenarios: Lignin has a value of $0.15 per pound, and furfural has a value of $0.20 per pound, C5 sugar are fermented to ethanol. The high and low values ranged from $3.56 to $1.42.

The low value was with substantial by-product credits lignin and C5 products. Sensitivity analyses on the base case showed that the sum of the effects from improved enzyme activity, increased hydrolysis efficiency and sodium hydroxide recovery can potentially reduce the selling price of ethanol by another $0.50 per gallon.

3 Technology: Current Status

The single important fact to emerge from the engineering studies is that for any process for conversion of lignocellulosic biomass to ethanol to be economically feasible will require utilization of all three major fractions of the feedstock. In certain scenarios the ethanol becomes the by-product and products of the xylose and lignin streams are the principal revenue generators for the plant. In any case the use of these fractions is necessary for economic feasibility.

High temperature acid processes convert as substantial amount of the xylose to furfural and condensation products with lignin (tars), and induce additional condensation of the lignin itself. These processes are useful if you want to make furfural as a product, however, highly condensed lignins have lower (and maybe no) value in polymer and resin applications. One would be justified in questioning the economic potential of high temperature acid hydrolysis processes based on the low level of feedstock utilization. Concentrated acid processes provide clean byproduct streams and therefore have good potential for economic success if the acid recycle problem can be solved.

Three operations in enzymatic process seem to offer opportunity for substantially reducing the production costs of ethanol; (A) the pretreatment section, (B) the enzyme production section, and (C) the hydrolysis/fermentation section.

A. Pretreatment:

In enzymatic hydrolysis processes the hydrolysis system functions under very mild conditions and should not modify the hemicellulose and lignin fractions of the feedstock. However, the pretreatment will have some degree of interaction with all three fractions. Three general types of pretreatment are used in enzyme processes: (1) Dilute acid, (2) Steaming, with and without explosion, and (3) Organosolv.

1. Dilute acid pretreatment uses a mild acid solution(1 to 2 percent sulfuric)at about 160°C to remove about 80 percent of the hemicellulose and open the structure of the feedstock for easier enzyme attack on the cellulose.

2. Steaming pretreatment, generally call steam explosion, disrupt the structure of the substrate and yields a lignin that has superior properties and market value. Some of the hemicellulose is converted to furfural during the process reducing the amount of xylose

available for down stream processing. Water washing the pulp removes most of the remaining xylose along with water soluble lignin fractions and acetic acid and other degradations products. This wash stream requires a lot of clean up if the xylose is to be used for animal feed or as a fermentation feed. The cellulose from the process has excellent susceptibility to enzymic attack.

3. Organosolv pretreatment uses an organic solvent and water mixture to remove the lignin and hemicellulose fractions and leaves an easily attack cellulose cake behind. This pretreatment is the most expensive to operate, however, it does offer the best means to control the quality of the lignin for downstream processing. A relatively clean xylose stream is obtained during the process. If several high value markets for lignin are identified, that require different properties in the lignin, then the organosolv process may provide the best method for generating the lignin.

B. Enzyme Production:

The high cost of enzymes is a problem area in these processes. Recent advances in cellulase productivity have been made using a liquid feed(lactose sugars) as the carbon source and have produced rates in the range of 400 to 500 I.U./l per hr.(International Units per liter per hour).

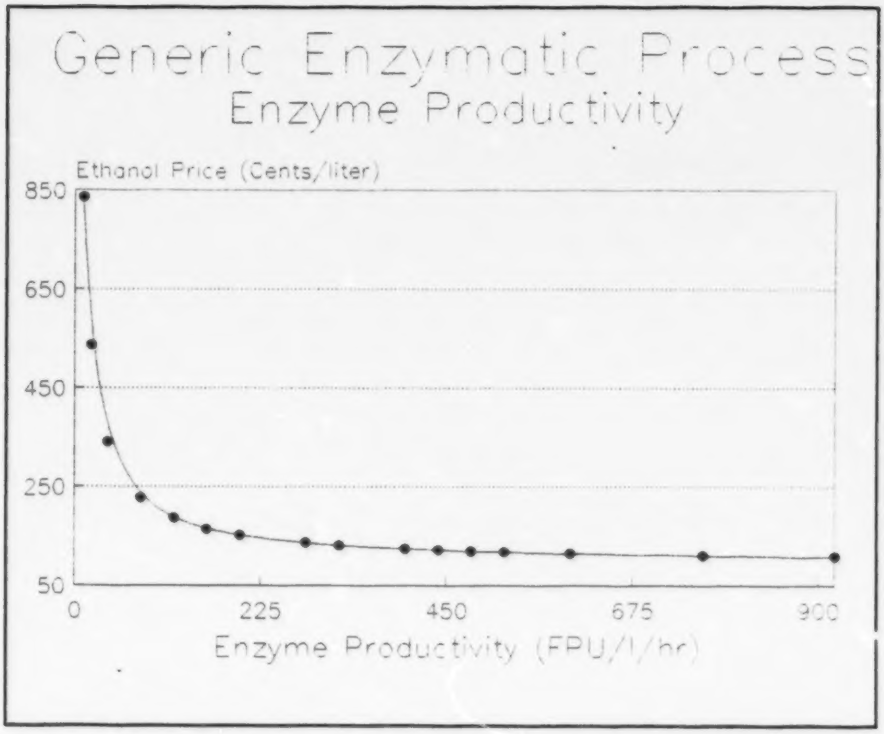


Figure b3. Enzyme Production versus Ethanol Price

The highest growth rates published for producing cellulases on a solid substrate is in the range of 50 to 100 I.U. per liter per hr., growing on pretreated lignocellulosic materials the values are in the range of 25 to 50 I.U. per liter per hr. Figure b3 shows the impact of enzyme productivity on the selling price of ethanol for a generic SHF process. The general trend will be the same for any enzymatic process of the SHf and SSF type. The figure shows the selling price of ethanol at 25 I.U. per liter per hr to be about $8.00 per liter and at 400 I.U. per liter per hr it drops to about $1.20 per liter. Therefore, high enzyme productivity is one key to successful commercial development.

There is a problem with using lactose as the sole carbon source for enzyme production, which is the lack of sufficient lactose to economically supply a single commercial scale plant in the 25 to 50 million gallon per year size. In fact, it was a limitation of available lactose that determined the scale of 5.5 million gallons per year for the plant in the A.D. Little feasibility study. Recent research has shown that xylose and glucose under certain conditions will produce cellulase enzymes at high growth rates. Building on the experience of the lactose research data growth conditions may be developed for using xylose or glucose as the carbon source for cellulase production. New microorganisms have been developed in the last two or three years that grow faster on solid substrates and should aid enhanced development of this activity.

C. Hydrolysis/Fermentation:

An alternative to producing enzyme at higher rates is to increase the activity of the enzyme. Figure 4 shows the effect of enzyme loading on the selling price of ethanol.

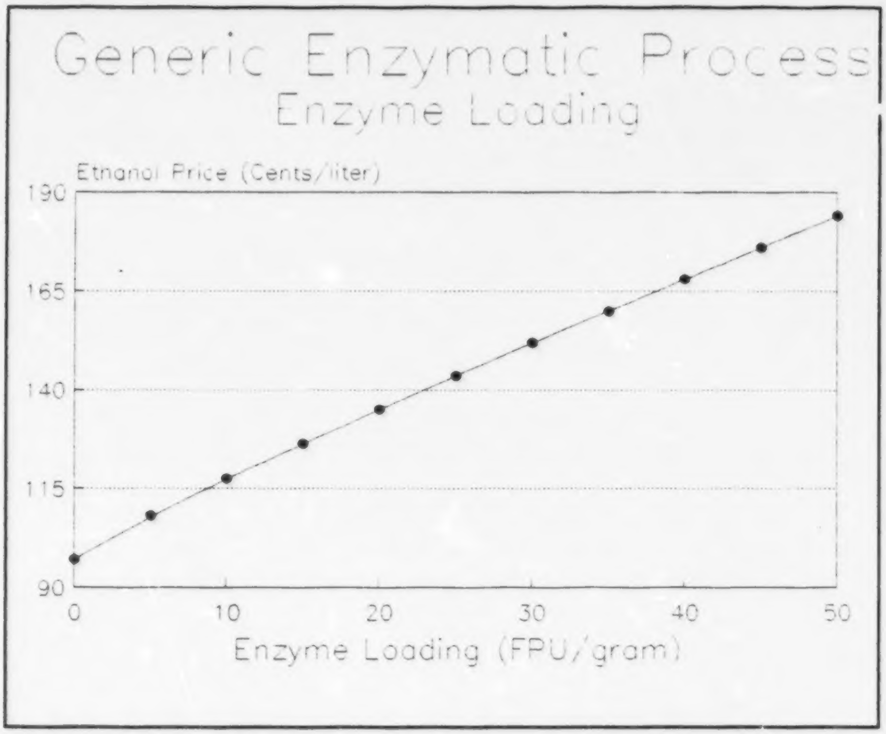


Figure b4. Enzyme Loading versus Ethanol Price

At 30 I.U. per gram of substrate the selling price of ethanol is $1.50 per liter and at 10 I.U. loading the selling price drops to $1.15 per liter. It is obvious that if we need less enzyme, to produce the same glucose yield, the cost of producing ethanol is reduced. There are three ways to accomplish this goal: (1) change the protein complex of the enzyme mixture to include more of the active components, a genetic engineering problem, (2) greatly enhance the susceptibility of the cellulose by improved pretreatment, a chemistry problem, and (3) use the SSF process to minimize the enzyme requirements and increase the glucose yield, a biochemical engineering problem.

Note: Enzyme recycle would produce a similar reduction in ethanol price, however, to date no effective recycle system has been developed and tested.

All three of these options of technical feasible and the subject of intensive research worldwide. Incremental improvement have been made in enzyme activity and to the effectiveness of pretreatment processes, however, the major change in process technology in the past two or three years is the development of functional SSF systems. In recent tests the performance in SSF systems is limited by the temperature and ethanol tolerance of the yeasts and not by the performance of the enzyme (Wright 1988).

Conclusions:

There is every reason to be optimistic about the future of lignocellulose to ethanol processing as a viable commercial technology. The seems to be several technical and economic barriers, but nothing insurmountable, between the bench scale processes of today and industrial adaptation of the technology.

1. Without a major breakthrough in process technology, dilute acid process do not show promise for economic performance, even with co-product credits.

2. Concentrated acid processes look promising if..and it is a big IF.., very efficient and economical acid recycle processes can be develop.

3. The direct microbial conversion process using clostridia thermophilic bacteria does not seem to hold much promise because of significant technical and practical economic barriers.

4. The SHF and SSF enzymatic hydrolysis processes have potential for development into commercial processes if better enzymes and enzyme productivity, and more cost effective pretreatment can be developed. At present, the better near term option seems to be the

SSF approach. The economic feasibility of either of these enzymatic hydrolysis approaches depends on substantial income from by product revenues.

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Appendix C. Process Evaluation

Introduction:

The process of carrying a new technology from a research, bench-scale experiment to a commercial scale plant involves several steps, including engineering scale experiments to define the operating parameter for the pilot plant scale system, and finally the design and construction of a commercial scale facility. There are checks and balances at each step for deciding whether to proceed to the next scale-up level. The problem area is the step from the research and engineering scale to pilot scale, because this is the big step in terms of dollars and risk.

The purpose of process evaluation is to assess the economic potential of the new technology and determine the risk involved with additional scale-up. And thus, provide the decision maker with sufficient and appropriate information to determine the feasibility of continuing development.

2 Methodology:

Process evaluation can assist in answering the following engineering and economic questions:

- What performance, i.e., efficiencies, rates, costs, etc., must this process achieve to be a commercial success?
- What additional developments are needed to achieve the required performance?
- Can the required performance be accomplished without violating fundamental limitations, such as second-law of thermodynamics?
- What are the prospects for improvements in the process?

2.1 Process Synthesis.

The first task to complete in evaluating a new process is to synthesize a base case process flowsheet. This task involves defining each step in the process starting with the feedstock and ending with the final products of required quality and accounting for all waste streams and co-product streams. Then the following sequence of steps is completed:

- Draw the flow diagram (base case)
- Calculate the material balances
- Calculate the energy balances
- Estimate equipment sizes
- Estimate the capital costs
- Estimate the operating costs
- Evaluate the Base Case economics and potential profitability

The definition of the material balance is especially in this sequence. To the maximum extent possible, the work should be based on measured performance in integrated, continuous-flow experiments that are reliably supported by theory. Experience with large scale, pioneering plants in the chemical process industries has shown that material balances based on demonstrated performance are very influential in early achievement of design capacity and efficiencies. Such measurements are always incomplete the early stages of development, but the process engineer should work with whatever experimental data is available to assemble the material-flow picture with large-scale performance in mind.

With these step completed we have a base case process design and can determine the economic status of the new process given the current performance levels of the technology. These steps comprise the heart of any evaluation study and the quality of the subsequent results is determined by the amount process of engineering time allocated to these front end activities. Therefore, it is important to spend adequate time and study to assure this activity is properly completed.

2.2 Model Development.

The completion of the base case design should be viewed as a first step in an iterative process, in which future designs will be more refined, better focused and done with improved detail as better data become available. The base case design provides a basis for construction of a computer simulation model.

For illustrative purposes, lets use a generic wood to ethanol bioconversion process as a model system. This process uses steam explosion as the pretreatment and enzymatic hydrolysis for converting cellulose to glucose. The construction of a model for this process involves defining and mathematically coupling the stream flows and heat flows for the following nine operating units;

100	Wood Handling
200	Pretreatment
300	Enzyme production
400	Hydrolysis
500	Fermentation
600	Product purification
700	Product storage
800	Waste treatment
900	Utilities

The central design element of the computer simulation model is the material balance section. The material balance section contains all the mathematical relationships among the process streams entering and leaving each operating unit. Once the material balance equations are in place, the remaining elements of the model are constructed.

The energy balances and capital costs are calculated using stream sizes generated in the material balances. The input parameters, e.g., amount of wood per day, determine the scale of the operating units and, therefore, equipment size and cost. All of these factors combine to determine operating and capital cost and the production cost of the product ethanol and the economic impact of co-products.

The Lotus 1-2-3 spreadsheet computer program provides a very convenient format for developing a simulation model. The spreadsheet is set-up in rows and columns of cells. Each cell can contain mathematical equations and individual cells or groups of cells can be coupled together by these equations. It is this facility of the spreadsheet that allows us to construct the material balance section of the model. Blocks of cells and windows on the spreadsheet can be assigned specific functions or sections in the model and labeled for easy access.

The spreadsheet has a recalculation function and provides a simple method for evaluating the effects of changing any input value on the ethanol production cost. In addition, it is a simple matter to move around the spreadsheet model and see the impact of input changes on specific outputs, e.g., the effect of reducing the enzyme loading on the operating unit capital cost or the utility requirements.

2.3 Sensitivity Analysis

A good simulation model allows performance of sensitivity analysis and identification of the key parameters of the process. This model allows us to determine the impact of technical variations on the production cost of the product ethanol, with and without co-product credits.

Figure 1 shows the impact of changing the enzyme loading on the production cost of ethanol.

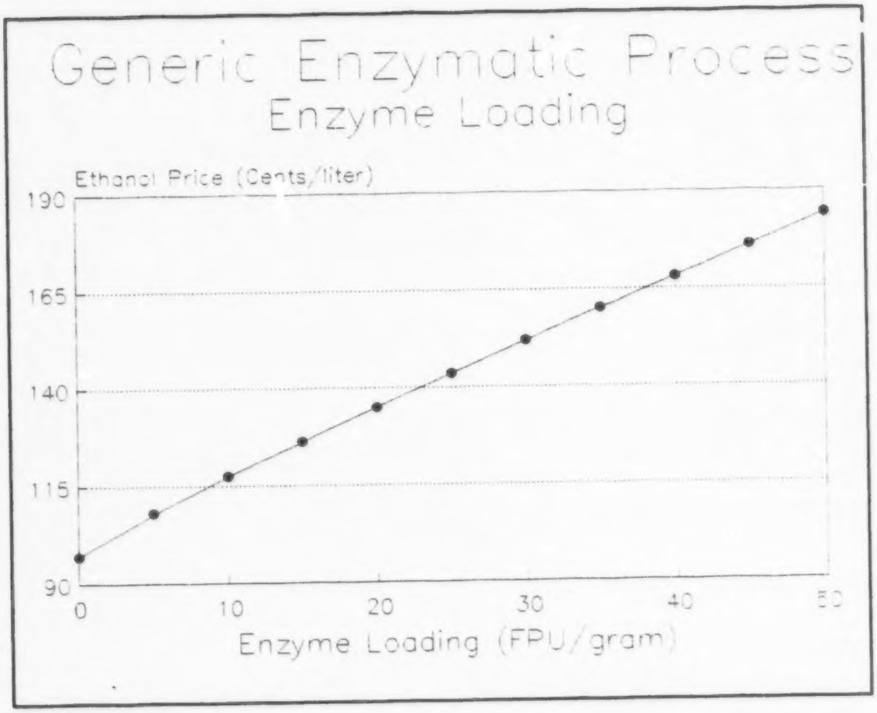


Figure 1. Enzyme Loading versus Ethanol Price

The base case value for enzyme loading was 30 I.U. per gram of cellulose (30 International filter paper units per gram of solid), which produced an ethanol production cost of $1.50 per liter. When the enzyme loading was reduced to 10 I.U. per gram the ethanol production cost was reduced to $1.20 per liter. If by some magic the hydrolysis step requires no enzyme the production costs are reduced to 95 cents per liter.

Figure 2 shows the impact of changing the enzyme productivity on the production cost of ethanol.

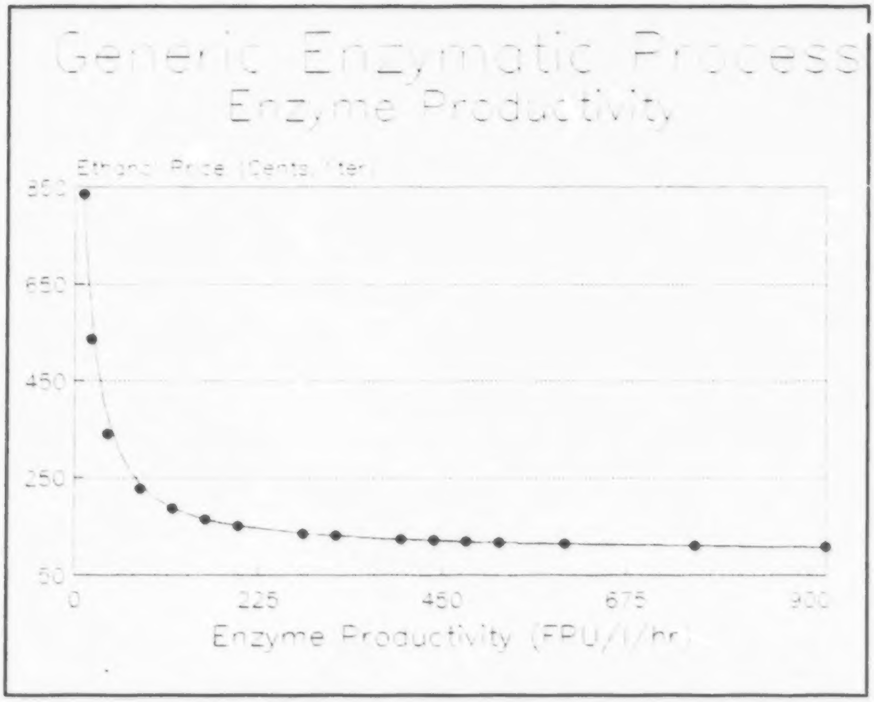


Figure 2. Enzyme Productivity versus Ethanol Price

The base case value of enzyme productivity in 130 I.U. per liter per hour and gave an ethanol production cost of $1.50 per liter. Increase the enzyme productivity to 400 I.U. per liter per hour reduces the ethanol production cost to $1.20 per liter, a further increase to 800 I.U. per liter per hour reduces the cost to $1.00 per liter.

Clearly, these two factors are very important to the economics of the process,
and the research/engineering strategy should include both variables. Both variables reduce the ethanol cost but they are interdependent, and therefore, we need to be careful in predicting the economic impacts of combining these two parameters. The section on Monte Carlo simulation addresses the issue of multi-variable analyses.

2.4 Monte Carlo Simulation

A question frequently asked is: Why use Monte Carlo simulation instead of simpler tools such as sensitivity analysis, CPM (critical path method) or PERT (performance evaluation and review technique)?

CPM and PERT are tools designed for schedule and cost analysis and do not provide forecast and risk analysis capability. Sensitivity analysis provides forecasting limited to one or two dimensions, but has no mechanism to directly assess the risk or uncertainty in the analysis. Monte Carlo simulation provides a method for completing multidimensional analysis and factoring into the analysis uncertainty in the form of a probability function.

The list below shows most of the key variables, in the generic ethanol process, that impact the production cost.

Enzyme Loading
Enzyme Productivity
% Solids Loading in SSF reactor
Hydrolysis Yield
% Lignin removal
Xylose fermentation to ethanol
Hydrolysis Residence Time
Enzyme Production Residence Time
Enzyme recycle

Most of the variables are interdependent. In attempting a complete process evaluation, sensitivity analysis, alone may be misleading. Additionally, showing the variation of more than two parameters at a time produces data that are difficult to visualize. More important, however, is that the valve of most variables in subject to some uncertainty.

The real strength of Monte Carlo simulation is the ability to handle both a large number of variables and permit assigning values for uncertainty of the data. This is especially important for forecasting improvements and refinement in emerging technology, where variable degrees of uncertainty always exist.

The Monte Carlo simulations are run on the same Lotus 1-2-3 spreadsheet model that the sensitivity analyses and later the second-law analyses will be run. Therefore, there is a level of internal consistency among the data for all the analyses. Figure 3 shows the output from a Monte Carlo simulation for a generic enzyme hydrolysis process.

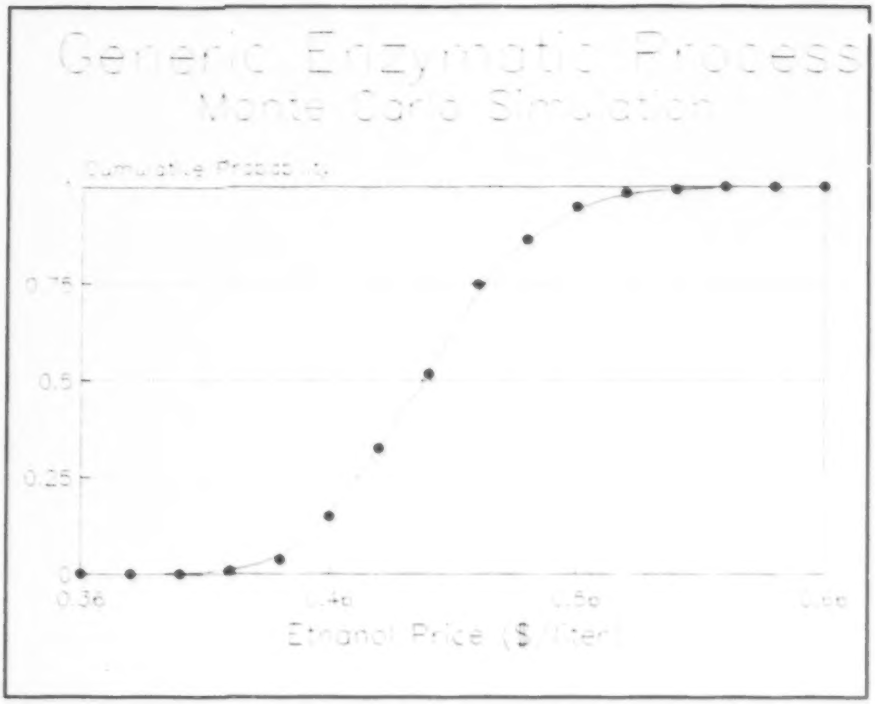


Figure 3. Monte Carlo Simulation: Improved Case

This result is for a highly improved case with xylose fermentation to ethanol and a lignin coproduct credit of 15 cents per liter. Note, from sensitivity analysis above, that the base case system produced ethanol for $1.50 per liter. The value for ethanol price at 0.5 cumulative probability is the "expectation" value and is 50 cents per liter in this case. The standard deviation was calculated from the data and found to be 4.5 cents per liter. Monte Carlo simulations produce a mean value for the variables used in the run and produce a "risk" factor or standard deviation that, in this case, says the predicted ethanol price will be 50 cents per liter plus or minus 4.5 cents per liter for 1 sigma or 67 percent of the time and 50 plus or minus 09 cents per liter for 2 sigma or 95 percent of the time. This representation means there is a 95 percent probability that the production cost of ethanol will fall between 41 and 59 cents per liter using the assumptions of the simulation.

2.5 Second-law Analysis.

The second-law analysis provides a thermodynamic basis for evaluating the potential for process improvements. The second-law analysis generates an estimate of the energy efficiency of the individual operating units and the overall process efficiency. The measure that is used to assess the energy performance of the process is called lost work and is a combination of the first law heat efficiency with the second-law efficiency and yields, the lost work function, a more intuitive monitor of process improvement. Lost work is the amount of work produced in the process subtracted from the potential work available from the process. Figure 4 shows the second-law analysis for an improved case of the generic enzymatic process. This result was generated under the same conditions as used in the Monte Carlo simulation result shown above.

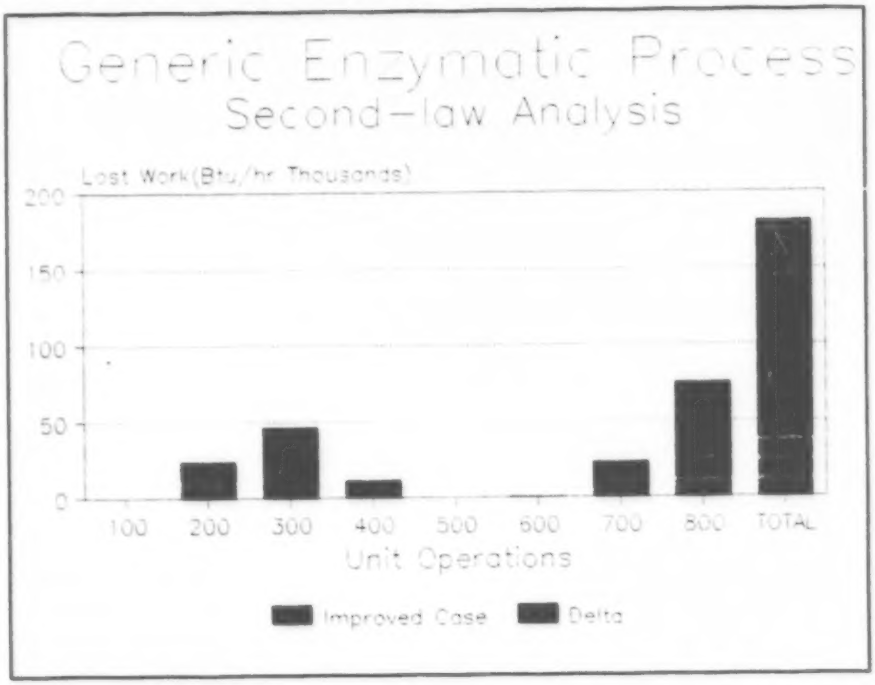


Figure 4. Second-law Analysis: Improved Case

The results shown in figure 4 demonstrate the that potential for improvements to the second-law efficiency of the process are quite large when compared to the base case.

The basic message is that we are not near a thermodynamic barrier in the process, when going from the base case to the improved case. Looking at the improved case shows that there is still room for further improvements. The total height of each bar represents total lost work in the base case and the bar represents the improved case.

```
                    01 FEEDSTOCK HANDLING 100 UNIT - ON GRADE
                       E Q U I P M E N T  L I S T

-------------------------------------------------------------------------------------------------------
                                                                                              PURCHASED
ORIGIN  EQUIPMENT         I T E M           - - - - - -  D E S I G N  D A T A - - - - - - - - -EQUIPMENT
        ITEM TYPE   D E S C R I P T I O N                                                     COST
-------------------------------------------------------------------------------------------------------
CO -101  CONT-BKT-L CHP CNVYR GE-103 (6) ITEM  MATERIAL        CS            - RATE          216.00   TPH    226800
                                               LENGTH       100.00  FEET     - DRIVER POWER   50.00   HP
                                               WIDTH         18.00  INCHES   - TOTAL WEIGHT 14800     LBS

CO -102  CLOSED-BLT BELT CNVYR GS-102          MATERIAL      A285C           - CAPACITY       60.00   TPH     49000
                                               LENGTH       330.00  FEET     - WIDTH          18.00   INCHES
                                               DRIVER SPEED 1750.00 RPM      - DRIVER POWER    5.00   HP
                                               SPEED        300.00  FPM      - NO. SECTIONS          1
                                               TOTAL WEIGHT    12500 LBS

VS -103  ONE DECK   VIB SCRN GF-103 (3)  ITEM  MATERIAL      CS              - LENGTH         24.00   FEET    75300
                                               WIDTH           8.00  FEET    - DRIVER POWER   25.00   HP
                                               TOTAL WEIGHT 15100    LBS

S -108   TRUCK      TRUCK SCALE GV-108         MATERIAL      CS              - CAPACITY       60.00   TONS    44400
                                               TOTAL WEIGHT 34500    LBS

S -109   TRACK      TRACK SCALE GY-109         MATERIAL      CS              - CAPACITY       60.00   TONS    42200
                                               TOTAL WEIGHT 56500    LBS

CP -101  AVS-LOW    FLUME PUMP PP-101          MATERIAL      CS              - CAPACITY     2000.00   GPM      6800
                                               HEAD          15.00   FEET    - TEMPERATURE   120.00   DEG F
                                               DRIVER POWER  20.00   HP      - SPEED        1200.00   RPM
                                               TOTAL WEIGHT  1600    LBS     - INCLUDES MOTOR DRIVER

GM -104  GM104      FRONT ENDLOADER GM104 ABS  NO. OF ITEMS          3       - TOTAL WEIGHT    10000 LBS    294915

GS -105  GS105      MAGNETIC CHIP CLNR GS105   NO. OF ITEMS          1       - TOTAL WEIGHT     2000 LBS      8403

GM -106  GM106      YARDSWITCHINGENG GM106AB   NO. OF ITEMS          2       - TOTAL WEIGHT    40000 LBS   1282240

GY - 107 GS107      WOODCHIPTRKUNLDR GY107     NO. OF ITEMS          1       - TOTAL WEIGHT     5000 LBS      8548
```

```
1 EQUIPMENT LIST             03 STEAM EXPL GUNS SYSTEM -
-----------------------------------------------------------
CO-101 CLOSED BLT        MAT:  33000.
INCLINED CNVYR FDR  W10MHRS:  26259
        6800 LBS        LAB:  3863.

CO-102 CLOSED-BLT        MAT:  23400.
PRTRMT FEED CNVYR   W10MHRS:  135ES
    3600 LBS            LAB:  1985.

CO-103 CLOSED-BLT        MAT:  53200.
DSCJGCVS W104A-B (2)ITEMHRS:  36GES
    4700 LBS            LAB:  2213.

CO-105 SCREW            MAT :  43800.
DSCJGCVS W104A-F (6)ITEMHRS:  150ES
   8:0 LBS             LAB :  2213.

CO-105 SCREW             MAT:  318000.
PRODCNVS W105A-F (6)ITEMHRS:  150ES
      5700 LBS          LAB:  2213.

CO-106 CLOSED-BLT        MAT:  97400.
CENTRL CONVYR W106  %=20MPRS: 378ES
      12400 LBS         LAB:  5571.

T-102 CYLINDER          MAT:  6400.
SULFACID STRS TANK  M10MHRS:  25ES
    3400 LBS            LAB:  369.

CP-201 AVS-MEDIUM       MAT : 4600.
ANRB DIG FEED PMP  P201MHRS: 55ES
    1100 LBS           LAB : 807.

CP-201 AVS-MEDIUM       MAT : 4600.
ANDIGFEEDPUMP P201B SPARMHRS: 51ES
    1100 LBS           LAB : 758.

CP-202 AVS-MEDIUM       MAT : 4300.
LGNCENTRF FDPMP    P202MHRS: 51ES
    1100 LBS            LAB: 758.

CP-202 AVS-MEDIUM       MAT : 4300.
LGNCENTFDPMP P202B  SPAREMHRG: 51ES
    1100 LBS           LAB :  758.

CP-203 AVS-MEDIUM       MAT  :  6500.
WASH FEED PUMP     P203MHRS : 663S
    1700 LBS           LAB  :  978.
```

The second-law analysis is more of a supporting tool in the evaluation process, that says the assumptions made during the sensitivity analyses and Monte Carlo simulations are reasonable and do not violate basic thermodynamic principals.

3 Summary:

The procedures described in this short review are similar to conventional engineering per economic evaluations used to analyze any new process moving from the research scale to engineering scale. The development of a computer simulations model provides a facile method to look at, and screen different scenarios for the operation of the new process.

The real benefits derived from this type of program are identification of important research areas along with the definition of the potential economic impact of the successful completion of the research objectives. Even more important, this type of evaluation process can identify technology research areas with minimal or no economic impact, and save wasted dollars by directing concentration of resources on more productive activities.

Appendix D. Lotus 1-2-3 Computer Simulation Model

Introduction

A major part of the process for evaluating the Iogen Wood to ethanol bioconversion process was the development of a computer simulation model using the Lotus 1-2-3 spreadsheet software. The computer model was the basis for all subsequent analysis of the process, which included sensitivity analyses, Monte Carlo simulations.

The model was developed to simulate the Iogen separate hydrolysis and fermentation (SHF) process. The function of the computer model is to provide insight into the economic drivers in the process and identify, through sensitivity analysis, the process parameters to include in Monte Carlo simulations.

2 Process Description

The Iogen wood-to-ethanol process is an enzymatic hydrolysis system that uses the Separate Hydrolysis and Fermentation (SHF) approach with the purpose of converting woody substrates into ethanol. The process consists of several steps (or unit operations):

1. Pretreatment
2. Enzyme Production
3. Hydrolysis
4. Fermentation
5. Distillation
6. Waste treatment
8. Heat generation

The pretreatment used is steam explosion of the substrate followed by a water wash and then an alkali extraction of the lignin as an option.

The enzyme production is carried out in stainless steel batch reactors and uses lactose from cheese whey as the carbon source. A fungal cellulolytic microorganism is used to produce the cellulase enzymes. Xylanase enzymes are co-produced in this step and in some configurations of the process generate a xylose stream that can be extracted as a separate by-product for use as an animal feed.

Hydrolysis is carried out in batch reactors and involves adding cellulase enzymes to the cellulose from the pretreatment step.

After liquefaction and hydrolysis of the cellulose and lignin mixture the hydrolysate is filtered to remove the lignin and the filtrate sent to the fermentation tank. Yeast is added to the fermentation reactor to convert the hydrolysis product, glucose, to ethanol.

The beer produced in the fermentation step is sent to the distillation section where it is purified to fuel grade ethanol. The still bottoms (a waste stream) is sent to the waste treatment section (or to a concentration step if the stream is to be used as an animal feed).

The waste treatment section in the present configuration is a concentration step using multi-effect evaporators, however, an alternate scheme is to send this waste to a settling pond.

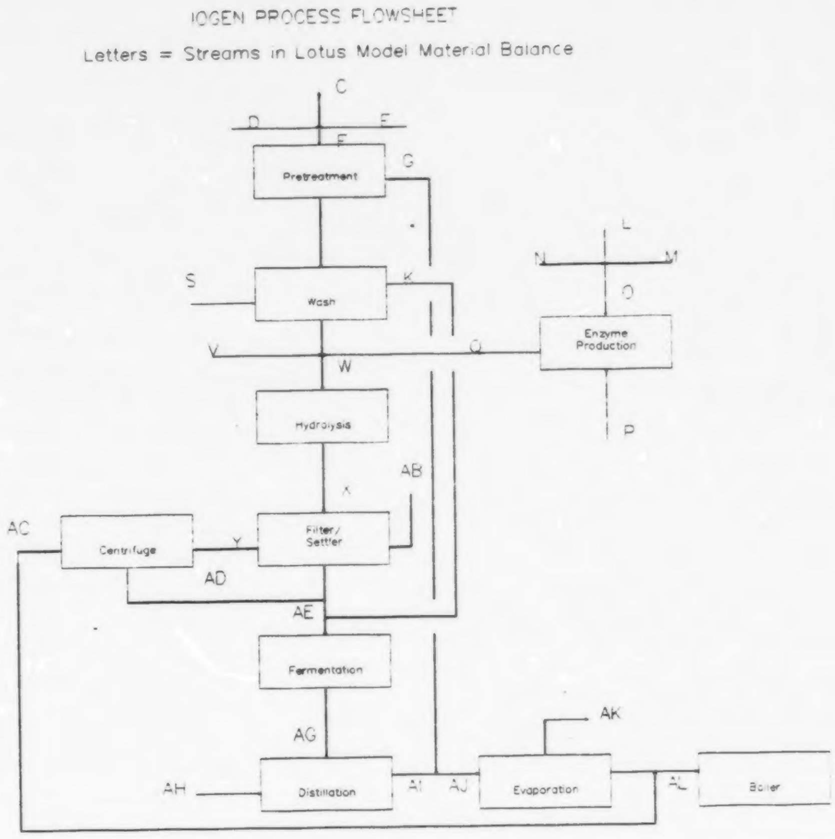

IOGEN PROCESS FLOWSHEET
Letters = Streams in Lotus Model Material Balance
C
D
E
F
Pretreatment
G
L
N
M
S
Wash
K
O
V
Q
W
Enzyme Production
Hydrolysis
P
AB
X
AC
Centrifuge
Y
Filter/ Settler
AD
AE
Fermentation
AK
AG
AH
Distillation
AI
AJ
Evaporation
AL
Boiler

Figure d1. Iogen Process Flowsheet with Stream Numbers

A xylose fermentation section is part of the model and consists of batch fermenters that will use the xylose stream to yield additional ethanol. This feature is an option in current process design and is not an active part of the current analysis because of the uncertainty of the processing parameters and fermentation yields.

Model Description

The simulation model was set-up on a Lotus 1-2-3 spreadsheet software. The heart of the model is construction of the material balance equations on the basis of the base-case design information. Each stream of the process is defined and assigned a separate column in the material balance section of the model. With the material balance completed the remainder of the model is assembled and coupled to the material balance. The completed model has defined input and output sections, with the mathematical relationships built-in so that changes in any input variable will be reflected in the resultant output values.

Model Layout

The model is constructed in a modular form with specific windows defined for individual functions of the model. The position and function of some of these windows is defined in the following three sections.

The central sections of the model are the material balance, the equipment costs and the utility costs. Once these value have been calculated, it is possible to determine the economic posture of the process relative to the base-case.

Material balance

The total material balance extends out about seven windows and contains every stream in the process. This is the center piece of the model and nearly every other calculation in the model depends on this section is some manner. Therefore, much of the energy required to assemble this model went into the development of the material balance and associated relationships and equations developed from the base-case design.

First Window of the Process Material Balance

	Feed 1	Acid>	HP Steam	Gun>
Water	61111	44000	22241	127352
Hexose	44000			41800
Xylan	22458			4043
Lignin	21542			21046
Sol solids	3667			4162
Lime				
Gypsum				
Glucose				2200
Xylose				17967
Furfural				449
Degradation				
Ethanol				
Lactose		0		0
Cell Mass				
Enzyme				
Nutrient				
Solvent				
CO2/Air				
Total	152778	44000	22241	219019

Table d1 shows the first window of the material balance.

The first column in the table lists all the chemicals and major chemical species found in the process. The second column, labeled feed 1, is the input feed stream to the process. The feed stream contains 50 percent water and the balance is the break down in the wood components. The feed stream for the base-case is based on 500 tonnes per day of green wood (50 percent moisture).

Equipment costs

In this section the capital cost for the process is estimated based on the stream size change relative to the base-case. The stream size entering each of the unit operations is ratioed against the base-case stream size and a factor applied to determine the new capital cost for the unit. The result of this process is the new capital cost for the changed plant configuration. Table 2 shows the base-case costs and the calculated costs for the unit operations along with the exponent use in equation below.

Capital Equipment in $MM			
Section	Base	Exponent	Actual
Feed	7.9	0.8	7.9
Pretreatment	11.5	0.8	11.5
Enzyme Prod	29.4	0.95	29.4
Hydrolysis	30.2	0.8	30.2
Fermentation	2.9	0.5	2.9
Distillation	4.2	0.6	4.2
Offsite Tank	4.9	0.5	4.9
Environment	8.4	0.6	8.4
Utilities	37.0	0.8	37.0
	--------		--------
Total costs	136.3		136.3

Table d2 shows the base-case costs and the calculated costs for the unit operations along with the exponent use in equation below.

Costing equation:

NC = (BC)*(NS/BS)^ XF

where:

NC = New Costs
BC = Base Costs
NS = New Stream Size
BS = Base Stream Size
XF = Exponent factor.

Utilities

The utility section uses a procedure similar to that used for updating the capital cost factors, namely ratioed off the input stream to each of the unit operations. The factor for both steam and electricity are presented in MBtu per hour.

Utilities		Actual
Steam Section	(MBtu/hr)	Electricity (MBtu/hr)
Feed	0.3	1.3
Pretreatment	5.5	40.1
Enzyme Prod	14.6	25.5
Hydrolysis	9.8	0.0
Fermentation	2.0	5.0
Distillation	9.5	42.0
Offsite Tank	0.8	0.0
Environment	0.6	182.0
Utilities	10.7	6.9
	------	------
Total	58.8	313.9

Table 3 shows the utility requirement by plant section.

Input sections

The next four windows represent the input sections of the model and allow you to change any of numerous input parameters. It is these windows that the user will use in manipulating the model and doing sensitivity analyses. These windows include the input feed section, the pretreatment section, the enzyme production section, and the hydrolysis section.

Feedstock

This window allows us to specify the type of feedstock and the scale of the plant.

Wood Composition	Mixed Hardwood
Water	0.400
Hexose	0.288
Xylan	0.147
Lignin	0.141
Other	0.024

	1.000

Tonnes of Wood per Day = 1000

Table d4 shows the input feedstock composition (weight fractions) and the tonnes of oven dry feedstock going into the plant per day.

Process Energy Options

Extra Wood (Yes/No)	No	0 Tonnes/day
Natural Gas (Yes/No)	No	0 MMft^3/day
Process Residues (Yes/No)	Yes	Default

By-product Credit options:

Lignin (in/out = 1,0)	0
Molasses (in/out = 1,0)	0
Xylose Fermentation (Yes/No)	0
Enzyme Yield	250 I.U./g-lactose

The model has alternate methods for generating the utility requirement for the process. In the base case the process residues are dried and burned to provide the steam and electricity. The excess electricity is a by-product of the process. If the lignin and xylose streams are use to product co-products the process is deficient in energy.

The model is set up to use additional wood or natural gas to furnish the utilities. If either of these options is invoked these sources provide the total energy requirement of the plant and essentially no excess. Also, if either of the alternate sources of energy is selected the process residue switch is automatically turned off. All of these options are coupled the material and utility balance, and capital costs sections.

The window also contains the option keys for extracting the by-product lignin and/or molasses and assigning a value to each in cents per Kg credit against the selling price of ethanol. Xylose fermentation is also added as an alternate process and method for handling the xylose stream.

Pretreatment

In this section the operating parameters for the steam explosion pretreatment are set. Once these parameters are set the model will use the built-in steam tables to calculate the utility value for steam consumed. In addition, the model has a facility to extract lignin if desired or leave the lignin in the system. Included in this facility is the ability to specify the amount of lignin removed, and the amount of caustic used to effect the lignin removal.

```
Pretreatment Conditions:(NOTE:  Steam tables located at $TABLES)

Steam Explosion Temperature (C)                         240.000TX
Flash Pressure (psia) (Flash T calculated)               75.000FP
Cellulose Yield (Steam Explo.)                            0.950YEX
Sol. Lignin Yield (Removal)                               0.023YSL
Furfural Yield (Lb/Lb Hemicell.)                          0.020YFCHO
Lb Stm./Ton Feed (@ 50% Moisture)                       880.000SGUN
Acid To Pretreatment                        0.000ACIDP
Soak Water (Lb/Lb Cellulose)                1.000WSOAK
Filt. Eff. (Solids)                         1.000EFFF
Wt. Fraction Water in Filtered Solids       0.650WFWFS
Filt./Centr. Eff. (Solutes)                 1.000EFFL
Lb. Wash/Lb. Solids                         3.000WSRT
Alkali Wash (0=NO/1=YES)                    0.000YESNO
Lignin Solubilized in Wash                  0.750YLW
Caustic or Lime (Lb./Lb. Lignin)            0.070CAUSTL
Centr. Eff. (Solids)                        0.975EFFC
Wt. Fraction Water in Centrifuged Solids    0.550 WFWCS
Wt. Fraction Water in Evaporated Solids     0.400WFWES
```

Table d5. Shows the input window for the pretreatment section.

Enzyme production

The major operational variables available in this section are effective solids in the reactor, enzyme titer, soluble protein, and residence time for growth. These variables can be change to produce a wide range of enzyme productivity and enzyme activity in order to simulate any growth system with modern microorganisms.

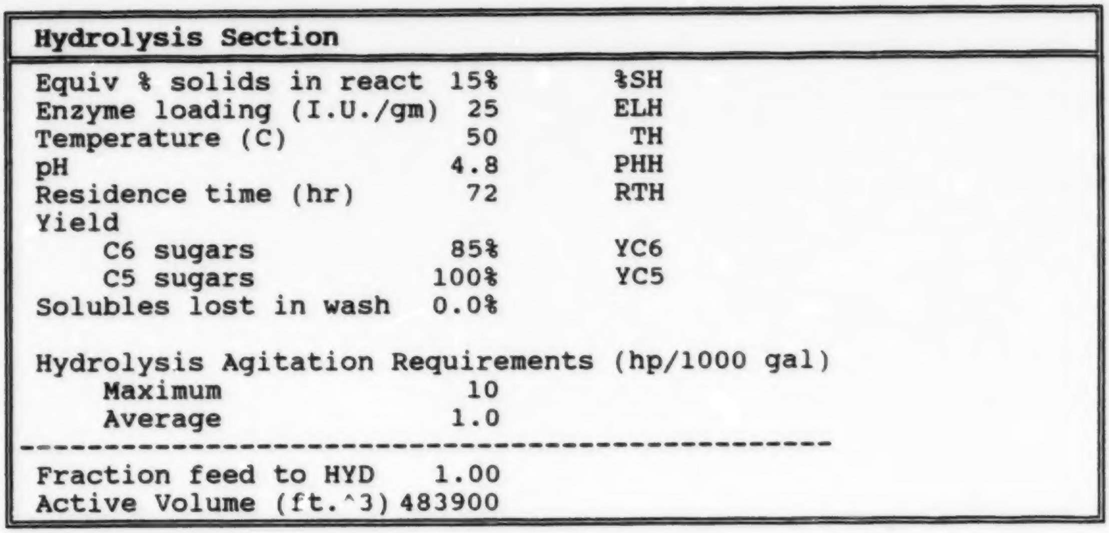
```
Enzyme Production Section:

Lactose in Whey (weight %)        20.0%         SL
Enzyme Titer (I.U./ml)             40.0         ET
Beta-G Titer (IU/I.U.)             20.0        BGT
Soluble Protein (g/l)              40.0         SP
Nutrients remaining                  0%         NR
Temperature C                        28        TEP
pH                                    5       PHEP
Residence Time (hr)                 100       RTEP
lb O2/lb Biomass                   0.89       O2/B
Btu/ lb Biomass                    5906      BTU/B
lb O2/lb Enzyme                     0.5       O2/E
BTU/ lb Enzyme                     2950      BTU/E
lb E/ lb Sub                        0.5        E/S
Final Cell Concentration (g/L)      10        BCEP
% fungal Growth in Seed Vessels 10.0%          FSV
Residence Time in seed vessels (hr)72         RTSV
Fermenter Height is 60 ft., active height is 51 ft.
```

Table d6 shows the window for imputing the values for enzyme production.

Hydrolysis

In the hydrolysis section we can vary the percent solids in the reactor, enzyme loading, residence time, and glucose yield from hydrolysis. The major impact parameters in this section are the percent solids in the reactor, the enzyme loading and glucose yield.



```
Hydrolysis Section

Equiv % solids in react  15%        %SH
Enzyme loading (I.U./gm)  25        ELH
Temperature (C)           50         TH
pH                       4.8        PHH
Residence time (hr)       72        RTH
Yield
    C6 sugars            85%        YC6
    C5 sugars           100%        YC5
Solubles lost in wash   0.0%

Hydrolysis Agitation Requirements (hp/1000 gal)
    Maximum               10
    Average              1.0
-----------------------------------------------
Fraction feed to HYD    1.00
Active Volume (ft.^3) 483900
```

Table d7 shows the window for modifying the hydrolysis section of the model.

Economic section

The economic summary includes feedstock and processing chemicals costs, utilities costs, estimates of labor and overhead, by-produce values (if applicable), the annual operating costs and capital charges, and the estimated production cost for ethanol in cents per liter. It is this bottom line ethanol selling price that is the ultimate measure of the effectiveness of research leading to proposed to improvements to the process.

	Units/liter	Cent/UnitA	Cost MM $	Cent/Liter
Wood Kg	3.7	4.2	14.00	15.34
Cheese Whey Kg	0.2	23	3.50	3.83
Lime lb.	0.0	1.75	0.00	0.00
Chemicals	0.0		2.32	2.55
Utilities				
Water 1000 liter	0.007	5.16	0.03	0.03
Steam	0.000	300	0.00	0.00
Labor hr.	0.001	1540	1.87	2.05
Overhead & Maint			8.88	9.73
By-products				
Xylanase Kg	0.000	12.1	0.00	0.00
Lignin Kg	0.000	22	0.00	0.00
Elect. (MWhr)	0.001	2920	-2.40	-2.63
Ann. Op Cost			28.20	30.90
Capital Charges			15.64	17.14
Ethanol Price			43.83	48.04

Table d8 shows the summary form of the economic output from the model.

Material input/output

This table combined with table 8 shows all the output data necessary to evaluate the total effectiveness of the process, both in terms of process efficiency and economic feasibility.

Materials Input and Process Outputs				
Inputs	**Kg/hr**	**Kg/yr.**	**Liters/hr**	**Liters/yr.**
Wood	41667			
Cheese Whey	1900			
Lime	0			
Water	76740			
Outputs				
Ethanol	9124		11405	91240398
molasses	0			
Lignin	0			
Elect. (MW)	10			
CO2	9274			
Input Data				
EtOH Production Rate	75045	600361819	11405	91240398
Operating rate (hr/yr.)	8000			
Convergence Ratio	0.0000%			
Convergence (gal/yr.)	0			

Table d9 shows the window with the number values for the major input variables and outputs for the process.

3 Operation of the Model

3.1 Lotus 1-2-3 Spreadsheet Model

The Iogen SHF Process

The base case design described in appendix A was use as the basis for constructing a computer model of the Iogen process. The model was developed on the Lotus 1-2-3 spreadsheet software and uses the same general format as the generic model described in milestone report number 2. The Iogen SHF model has several feature that were not part of the generic model, namely:

1. The model is feedstock driven, i.e., the amount of wood, in tonnes per day, entering the plant is one of the input variables.

2. The operator can choose to have lignin and molasses as by-products of the ethanol production or have these streams sent to the boiler to furnish process heat and electricity.

3. The model is also connected to the RETA economic analysis procedure and by selecting the (\R) macro it is possible to save the economic output in a RETA compatible file.

4. The model is menu driven such that by calling alt-M (\M) the menu macro, the operator can easily move to any section of the model. The menu facilitates selecting specific input and output section for review and analysis.

5. The cells containing input variables are highlighted for easy identification.

7.1.1 Menu Functions of the Model

The are three macros required to effectively operate the Iogen model; 1. Alt-Z the recalculation macro, 2. Alt-M the menu macro, 3. Alt-G the graphics macro.

1. The Alt-Z macro should be use to recalculate the model any time the amount of feedstock input changes. The reason for this requirement is that the basis of the model operation is an accurate calculation of the material balance and this occurs only when the

Alt-Z macro is invoked. Most of the mathematical interaction are independent of the amount of substrate and therefore do not require recalculation using Alt-Z to assure accurate up-dating.

For example, if the enzyme loading is changed from 25 I.U. per gram of cellulose to 40 I.U. per gram and no other changes were effected, the enzyme production section would increase in size to accommodate the increased amount of enzyme required. However, the amount of wood does not change and the basic material balance on wood would not change. This is a consequence of the independence between the wood stream and the enzyme production section of the process. Most of the process parameters behave in a similar manner and only require a function key 9 (F9) key board recalc. If in doubt use the Alt-Z macro, it only requires several seconds additional processing time.

2. The menu macro, Alt-M, call up to top line menu similar to the menus normally called in by the Lotus program, only in this case the menu allows the user to move around the spreadsheet model to selected areas. The menu has seven labels: 1. Input, 2. Cap_Cost, 3. EnzProd, 4. Summary, 5. Hydrolysis, 6. RETA_File, 7. Quit. Selecting any of these labels will move the user to that section of the spreadsheet model.

1. The Input section has three areas;

a. The feedstock composition,
b. The amount of feed input in tonnes per day, and
c. The by-product decision area, i.e., whether to extract lignin and molasses as by-product streams.
d. The Enzyme yield input level.

2. The Cap_Cost section contains the base case capital cost data and scale factors use to calculate the new capital cost when operating parameters are changed that effect plant or equipment sizes.

3. The EnzProd section contains the input assumptions used to determine the enzyme productivity. The principal parameters are enzyme titer, soluble protein, and fermentation time.

4. Summary is the section containing the output from the model and summarizes the economic components that add up to the ethanol production costs. This is the first level area for evaluating the economic impact of parametric changes.

5. The Hydrolysis section contains the input assumptions that control the rate of hydrolysis. The principal parameters are solids loading, enzyme loading, hydrolysis time, and hydrolysis yield. Each of these parameters has a significant impact on the economics of the process.

6. RETA_File is the section where the outputs from the model are stored in the format of the RETA economic model. The output from the RETA_File can be save in a separate (user-named) file for input in to the RETA model by calling the Macro Alt-R.

3. The Alt-G graphics macro is used to review the graphic data stored on the diskette in the form of named graphs. To invoke the macro push alt-g and a menu will appear at the top of the screen. The first item on the menu is VIEW, which asks the operator if he wishes to view the named graphs. Pushing return will bring up a list of the named graphs and by using the cursor keys the operator can select the graph he wishes to display. The graphs on the diskette are the sensitivity analyses and Monte Carlo simulation results.

3.2 Range Names and Location

Each of the windows shown in this review is a named range on the spreadsheet model. In order to go to any window just press F5 (Goto) and type in the range name or the cell location and return. For example, to go to the economic summary window type F5 followed by "sum" and return to bring up that section.

Window	Range Name	Location
Material Balance	MBal	A61
Equipment Costs	Cap	A81
Utilities	Util	G81
Feedstock	Feed	A21
Pretreatment	Pretreat	G21
Enzyme Production	Enzprod	H21
SSF (Hydrolysis Reactor)	HYD	AB21
Xylose Fermentation	Xylo	AH21
Economic Section	Econ	S1
Material in/out	IO	Y1

Table d10 lists the range names and cell locations for the windows and operating section discussed above.

3.3 Operating in two modes

There are actually two modes of operation for recalculating the models, one operates with a fixed input and the other operates with a fixed output. In most circumstances either model will provide a satisfactory (and essentially identical) result, however, the second-law analyses are much easier to complete with the fixed output model. The reason for this ease has to do with the manner in which the energies and enthalpies are calculated. Both model are available and produce similar sensitivity and Monte Carlo results. The choice between them involves fixing the output ethanol production and letting the model determine the amount of feedstock required, or selecting the amount of feedstock and allowing the model to determine the amount of ethanol that will be produced. The fixed input model is called IOGEN.WK1 and the fixed output model is labeled IOGENBK.WK1. Either model will run under Lotus 1-2-3 version 2.0 or 2.01.

4 Summary

This review paper defines the construction and operation of a computer simulation model developed on the Lotus 1-2-3 spreadsheet software. The Model simulates the Iogen SHF process for the bioconversion of woody biomass to ethanol and other fuel or chemical products. The spreadsheet approach as a vehicle for creating a process simulation model is a relatively new and powerful method for showing the economic changes caused by technical refinements to the process. The real advantage of the spreadsheet approach is the visual feedback afforded the operator, especially when the model is coupled to the graphical interface in the spreadsheet.

Appendix E. Attachment: Spreadsheet Print Out

The Appendix is a full, five page print out of the simulation model that shows all of the interactions and windows, and includes details not discuss in this short tutorial.

```
IOGEN SEPARATE HYDROLYSIS AND FERMENTATION PROCESS
Recalculate Spreadsheet with Macro ALT Z
                         -------------------------       CO2=       20403                                ^
Cheese whey -----------! Enzyme Production                          ^                                    ! EOH=      20403
             =       4180-------------------------                  !                                    !
                                   !                                !                                    !
                         -------------------------            -------------                        ------------
                        ! Hydrolysis                          Fermentation!                        !             Stillage
-----------------------># !    Eff CC         85.0%!---------->      Eff=  !----------------------->Distillation!-----------
Wood=               91667-------------------------                   95.0%!                        !               Water=
Water=             105111          !        !Water      452486-------------     Water=       452486 ------------  Solubles=
                                   !        !Gluc=       41630                Ethanol=        20174                Total=
                                   !        !Total      522355                  Total=       501953
                                   !        ! % C6         8.0%
                                   ^        !
               SlurryH2O=      229978       !
                Wash H2O=       41347  Lig/Cel/O=        27330
                    Acid=           0      Water=        33403
                   Steam=      152778
                 Caustic=           0
Assumptions
                                                              Pretreatment      (NOTE:  Steam tables located at $TABLES)
Wood Composition         Aspen wood (weight fraction)         STEAM EXPLOSION TEMPERATURE (C)                       250.000
Water                             0.4                         FLASH PRESSURE (PSIA) (FLASH T CALCULATED)                 75
Hexose                          0.288                         CELLULOSE YIELD (STEAM EXPLO.)                          0.950
Xylan                           0.147                         SOL. LIGNIN YIELD (REMOVAL)                             0.023
Lignin                          0.141                         FURFURAL YIELD (LB/LB HEMICELL.)                        0.020
Other                           0.024                         LB STM./TON FEED (@ 50% MOISTURE)                       600.0
                         -------------                        ACID TO PRETREATMENT                                    0.000
                                    1                         SOAK WATER (LB/LB CELLULOSE)                            1.000
Process Energy Source                                         FILT. EFF. (SOLIDS)                                     1.000
   Extra Wood (Yes/No)             NO         0.0 Tonnes/Day  WT. FRACTION WATER IN FILTERED SOLIDS                   0.650
   Natural Gas (Yes/No)            NO         0.0 MM Ft^3/Day FILT./CENTRA. EFF. (SOLUTES)                            1.000
    Process Residues              Yes     Default             LB. WASH/LB. SOLIDS                                     1.500
Feedstock Input =                1000 Tonnes/Day              ALKALI WASH (0=NO/1=YES)                                    0
Byproduct Credits                                             LIGNIN SOLUBILIZED IN WASH                                0.8
   Lignin(In/Out=Yes/No)           No           0             CAUSTIC OR LIME (LB./LB. LIGNIN)                        0.210
   Molasses(in/out=Yes/No          NO           0             CENTR. EFF. (SOLIDS)                                    0.975
   Xylose Fermentation             NO           0             WT. FRACTION WATER IN CENTRIFUGED SOLIDS                0.550
   Enzyme Yield                   250 I.U./gr lactose         WT. FRACTION WATER IN EVAPORATED SOLIDS                 0.400
        STEAM TABLES FOR FLASH CALCS. (See $temt)                    STEAM TABLES
                VALUE                    LOWER       DELTA      P (PSIA)       T (F)        HV       P (PSIA)     T (F)
FLASH TEMP            307                  300           7          14.7         212        970.3        17.2         220
H @ FT (BTU)         1180         905      910          -5          17.2         220        965.2        20.0         228
                                       FP - LOWER UPPER-LOWER       20.0         228        960.0        25.0         240
                                             8          23          25.0         240        952.1        35.4         260
                VALUE                    LOWER       DELTA          35.4         260        938.6        49.2         280
H @ THF(BTU)         1213         736      763         -27          49.2         280        924.6        67.0         300
                                       FP - LOWER UPPER-LOWER       67.0         300        910.0        89.6         320
TH (F)                482                   22          40          89.6         320        894.8       118.0         340
                                                                   118.0         340        878.8       153.0         360
                 Gun>    Flash vapor   >Cyclone                    153.0         360        862.1       195.7         380
BTU/LB                365        1180         214                  195.7         380        844.5       247.3         400
MMBH                   80          40          40 =MBHB (calc)     247.3         400        825.9       300.8         420
MMBH (sol)             14          40          14 = MBs            300.8         420        806.2       381.5         440
                       40          -1                              381.5         440        785.4       466.9         460
                                                                   466.9         460        763.2       680.9         500
      -0.81 <--------value of $BTU2                                680.9         500        714.3
            96870.63078
Multiplier= 91666.66666
                   Feed 1   Acid>       HP Steam        Gun>  Flash vapor   >Cyclone   Filter wash  Pretreat >  Xylose liq
Water               61111       44000       22241      127352        33484       93869       100333      124222       69980
Hexose              44000                               41800            0       41800            0       41800           0
Xylan               22458                                4043            0        4043            0        4043           0
Lignin              21542                               21046            0       21046            0       21046           0
Sol solids           3667                                4162            0        4162            0           0        4162
Lime                                                                     0           0            0           0           0
Gypsum                                                                   0           0            0           0           0
Glucose                                                  2200            0        2200            0           0        2200
Xylose                                                  17967            0       17967            0           0       17967
Furfural                                                  449            0         449            0           0         449
Degradation                                                              0           0            0           0           0
Ethanol                                                                  0           0            0           0           0
Lactose                             0                       0            0           0            0           0           0
Cell Mass                                                                0           0            0           0           0
Enzyme                                                                   0           0            0           0           0
Nutrient                                                                 0           0            0           0           0
Solvent                                                                  0           0            0           0           0
CO2/Air                                                                  0           0            0           0           0
Total              152778       44000       22241      219019        33484      185535       100333      191111       94758
Capital Costs                                                 Utilities               Actual
             Base        Exponent    Actual                               Electricity Steam
Section                                                       Section        (MBtu/hr)    (MBtu/hr)
Feed                  7.9         0.8         7.9             Feed                 0.3          1.3 Steam Produced (85%)
Pretreatment         11.5         0.8        11.5             Pretreatment         5.5         39.5 HP Steam to proc
Enzyme Prod          29.4         0.8        29.4             Enzyme Prod         14.6         25.5 50 Psig Steam to Proc
Hydrolysis           15.0         0.8        15.0             Hydrolysis           9.8          0.0 Condensing Steam > elect
Fermentation          2.9         0.5         2.9             Fermentation         2.0          5.0 Purchased Steam
Distillation          4.2         0.6         4.2             Distillation         9.5         42.1
Offsite Tank          4.9         0.5         4.9             Offsite Tank         0.8          0.0 Electricity Produced
Environment           8.4         0.6         8.4             Environment          0.6        182.0             50 psig
Utilities            37.0         0.8        37.0             Utilities           10.7          6.9             Condensing
            -------------            -------------            Misc.                4.0         11.0
                    121.2                   121.2                         -------------------------             Total
                                                                                  57.9        313.3             Export (MW)
```

```
                                                                                    Raw Materials           Units/ltr
                                                                                       Wood Kg                      3.7
                                                                                       Cheese Whey Kg               0.2
                                                                                       Lime Kg                      0.0
                                                                                       Chemicals                    0.0
            -------------                       -------------                       Utilities
               Waste    !                       !           !                          Water 1000 liters          0.007
-----------> Treatment  !----------------------->!  Utilities!                       Steam                      0.000
     452486             !                       !           !                          Natural Gas 1000 ft^3      0.000
      28349 -------------   Water=         52999 -------------                      Labor hr.                     0.001
     481880      !       Organics=         56724      !                             Overhead & Maint
                 !          Total=        109723      !                             Byproducts
                 !                                    !                                Molasses Kg                0.000
                 !                                    !                                Lignin Kg                  0.000
                 !                                    !                                Elect. (MWhr)              0.001

Water to:                                  Steam=   433390.9                        Ann. Op Cost
Recycle          233187               Elect (MW)=       27.3                        Capital Charges
Cooling Twr.      233187

            Enzyme Production                                                       Productivity (FPU/l/hr)       400.0
                                                                                    Enzyme Activity (FPU/gm)       1000
TX          Lactose in Whey (Weight %)                 20.0%          SL            Fraction of feed to EP       0.0000
FP          Enzyme Titre (FPU/ml)                       40.0          ET                                         FPU/hr
YEN         Beta-G Titre (IU/FPU)                         20         BGT            Total Enzyme production    4.74E+08
YSL         Soluble Protein (g/l)                       40.0          SP                                         FPU/HR
YFCHO       Neutrients remaining                          0%          NR
SGUN        Temperature C                                 28         TEP            Total Biomass Production      261.6
ACIDP       pH                                             5        PHEP            Production in Fed Batch        248.5
WSOAK       Residence Time (hr)                          100        RTEP            Production Seed System          13.1
EFFF        lb O2/lb Biomass                            0.89        O2/B
WFWFS       Btu/ lb Biomass                             5906       BTU/B
EFFL        lb O2/lb Enzyme                              0.5        O2/E            Fed Batch System
WSRT        Btu/ lb Enzyme                              2950       BTU/E            Active Fermenter Volume        41874
YESNO       lb E/ lb Sub                                 0.5         E/S            Cellulose Digested                 0
YLW         Final Cell Concentration (g/L)                10        BCEP            Oxygen Required (lb/hr)          744
CAUSTL      % fungal Growth in Seed Vessels             5.0%         FSV            Heat Evolved (MBtu)              4.6
EFFC        Residence Time in seed vessels (hr)           72        RTSV            Compression (hp)                 854
WFWCS       Fermenter Height is 60 ft, active height is 51 ft (aeration calc)       Agitation (hp)                  4687
WFWES
            Agitation (hp/1000 gal)
     HV        Maximum                                    15     AGEPMAX
      965.2    Average                                    15     AGEPAVG            Seed System
      960.0 VVM air to fermenters                        0.2         VVM            Seed Active volume (ft^3        1509
      952.1 Nutrients                                    g/L    Cent/lb C/lb EP BretOxygen Required (lb/hr)           12
      938.6 Corn Steep Liquor                             15        11.3      0.373 Heat Evolved (MBtu/hr)           0.1
      924.6 Sodium sulfate (monobasic)                   1.4         3.6      0.011 Compression (hp)                  31
      910.0 Potassium Phosphate (monobasic)                2         2.1      0.009 Agitation (hp)                   169
      894.8 Magnesium Sulfatex7H2O                       0.3         0.7      0.000
      878.8 Calcium Chloridex2H2O                        0.4         4.7      0.004 Energy Consumption
      862.1 Tween 80                                     0.2          73      0.032 Electrical                        hp
      844.5 Antifoam                                       1          25      0.055       Agitation                 4856
      825.9                                     ------------            ------------      Compression                885
      806.2                                             20.3                  0.583       Pumps, etc                   0
      785.4                                              M/L               CN/LBEPB                                 5741
      763.2 Ammonium Hydroxide                            20          10      0.529 Steam Consumption
      714.3                                                             ------------      Cooling Water
                                                                              1.111
                                                                           CC/LBEPB

> Enz Prod   H2O > EP Nutrient>EP   >Fermenter Air > Ferm      EP>Hyd Feed > Hyd  Fred>Hyd Dir  Feed > ER SolidER>Hyd
     16720       8116                    24836                   24836     124222        124222          0           0
         0                                   0                       0      41800         41800          0           0
         0                                   0                       0       4043          4043          0           0
         0                                   0                       0      21046         21046          0           0
         0                                   0                       0          0             0          0           0
         0                                   0                                  0             0          0           0
         0                                   0                                  0             0          0           0
         0                                   0                       0          0             0          0           0
         0                                   0                       0          0             0          0           0
         0                                   0                       0          0             0          0           0
         0                                   0                                  0             0          0           0
         0                                   0                                  0             0          0           0
      4180                                4180                       0          0             0          0           0
         0                                   0                     249          0             0          0           0
         0                                   0                    1045          0             0          0           0
         0                    531          531                                  0             0          0           0
         0                                   0                                  0             0          0           0
         0                                   0      42054                       0             0          0           0
     20900       8116         531        29547      42054        26129     191111        191111          0           0
                                                            Base Case
                                                            Electricity Steam
  (MBtu/hr)                         Section                 (MBtu/hr)   (MBtu/hr)
      433.4                         Feed                            0.3         1.3
       39.5                         Pretreatment                    5.5        56.3
      273.8                         Enzyme Prod                    18.1         0.0
      120.1                         Hydrolysis                      8.3           0
        0.0                         Fermentation                    2.0         5.0
                                    Distillation                    9.5        42.0
                   (MW)             Offsite Tank                    0.8         0.0
       54.8        16.0             Environment                     0.6       182.0
       38.4        11.3             Utilities                      11.0         7.1
------------                        Misc.                           4.0        11.0
       93.2        27.3                                     ------------------------
       10.4        10.4                                            60.1       304.7
```

```
Cent/Unit   A Cost MM $   Cent/ltr  Inputs                  Kg/hr       Kg/yr          ltr/hr       ltr/yr   Economic Ass
        4.2       14.00       15.34    Wood                       41667
         23        3.50        3.83    Cheese Whey                 1900                                      ANL Uniform
       1.75        0.00        0.00    Lime                           0                                      Inflation
                   2.32        2.55    Water                      76740                                      Fract. bond
                                                                                                             Fract. Stock
       5.16        0.03        0.03 Outputs                                                                  Cost of Fund
        300        0.00        0.00    Ethanol                     9124                    11405    91240398 IRR
        130        0.00        0.00    Xylose Syrup                   0                                      Tax rate
       1540        1.87        2.05    Lignin                         0                                      Real Funds
                   8.88        9.73    Elect. (MW)                   10
                                       CO2                         9274                                      Const. (yr.)
       12.1        0.00        0.00                                                                          Dep. (yr.)
         22        0.00        0.00 Input Data
       2920       -2.42       -2.65                                                                          Ko/CAP=
            ------------------------EOH Production Rate           75045    600361819       11405    91240398 TDCF/CAP=
                  28.18       30.88 Operating rate (hr/yr)         8000                                      CCIF
                  15.64       17.14                                                                          1982/1984
            ------------------------Convergence Ratio           0.0000%                                      FCR=
                  43.81       48.02 Convergence (gal/yr)              0
        EPP                         Enzyme Recycle  - 'Section Disabled'                                     Hydrolysis
         EA
       FFEP                         Enzyme Recycle Included? (0,1)                                 0         ERT Equiv % soli
    lb E/hr  1 broth/hr ~lb broth/hrFraction of Enzyme Recovered from Drained Liq             0         FEA Enzyme loadi
       1045       11061       26129 Fraction Process Feed to Enzyme Recovery                   0       FPFEA Temperature
     LBE/HR                LBEPB/HR                                                            0      TEMPER pH
        BEP                         % Solids in Drained Hydrolysis Residue                   0.2       %SDHA Residence ti
        BFB                         Fraction Liq in Drained Liquids                         0.75             Yield
        BSV                         Fract Enzyme actually recovered                            0        FEAR      C6 suga
                                                                                                                  C5 suga

                                                                                                             Solubles los
     AVFBEP                                                                                                  Hydrolysis A
                                                                                                                  Maximum
                                                                                                                  Average
                                                                                                             ------------
     CPFBEP                                                                                                  Fraction fee
     AGFBEP                                                                                                  Active Volum

                                                Liq in EP   SolidER>Hyd     EP> Liq FLSolids               0 Power Consum
                                    Water                 0           0           0
                                    Hexose
     AVSSEP                         Xylan
                                    Lignin
                                    Sol solids            0           0           0
     CPSSEP                         Lime                  0           0           0
     AGSSEP                         Gypsum                0           0           0
                                    Glucose               0           0           0
                                    Xylose                0           0           0
       MBtu                         Furfural              0           0           0
         12                         Degradation           0           0           0
          2                         Ethanol               0           0           0
          0                         H2SO4                 0           0           0
         15                         Cell Mass             0           0           0
                                    Enzyme                0           0           0
         25                         Nutrient              0           0           0
                                    Solvent               0           0           0
                                    CO2/Air               0           0           0
                                    Total                 0           0           0
Water>Hyd 3 > Hyd React    Reactor> DrainedSolidDrained Liq    ER Liq >  Wash Water    Lignin 9 Hyd<Cont 10    >Ferm 13
     229978      379036      374562       98412      276150      276150       41347       33403      106356      452406
                  41800        6270        6270           0           0                    6035                       0
                   4043           0           0           0           0                       0                       0
                  21046       21046       21046           0           0                   21046                       0
                      0           0           0           0           0                       0           0        4162
                      0           0           0           0           0                       0           0           0
                      0           0           0           0           0                       0           0           0
                      0       39438       10362       29076       29076                       0       10362       41638
                      0        4608        1211        3398        3398                       0        1211       22575
                      0           0           0           0           0                       0           0         449
                      0           0           0           0           0                       0           0           0
                      0           0           0           0           0                       0           0           0
                      0           0           0           0           0                       0           0           0
                    249         249         249           0           0                     249           0           0
                   1045        1045         275         770         770                       0         275        1045
                      0           0           0           0           0                       0           0           0
                      0           0           0           0           0                       0           0           0
                      0           0           0           0           0                       0           0           0
     229978      447218      447218      137824      309395      309395       41347       60733      118203      522355
```

```
unptions

 Cost Estimation Assumptions
        8.5%
        0.3 Yield               13.0%
        0.7 Yield               15.0%
                                14.4%
       15.0%  (after tax)
        0.45
      0.0792

          2
         20

      1.070 S-                  1.062
      0.913
      1.172
      0.956
      0.129 w/ ARCS & 10% invest tax credit,
            ANL FCR=0.11
                                                            Fermentation

ds in react          15.0%      ZSH
ng (FPU/gm)             25      ELH                         Glucose                             % theory    wt. %
(C)                     50       TH                         CO2 evolution                              1        0.49
                       4.8      PHH                         Fermentation efficiency                 0.95      0.4845
me (hr)                 72      RTH                         Conversion to other solubles            0.05      0.0255
                                                                                               Should add to 2
rs                     85%      YC6                         Xylose                                     0
rs                    100%      YC5                         CO2 evolution                              0           0
                                                            Fermentation efficiency                    0           0
t in wash             0.0%                                  Conversion to other solubles               0           0
gitation Requirements (hp/1000 gal)
                        10                                  Standard Batch Fermentation
                         1
-----------------------------------------------------------
d to HYD            1.0000                                  Distillation
e (ft^3)            516021                                  Ethanol Recovery Eff           99.5%

ption                   hp   MBtue/hr                       Operating Cost Assumptions
                      3860         10
                                                            Labor & Overhead             0.001 (manhr/yr) / $ Capital I
                                                            Maintenance                  0.040 * Capital Investment
                                                            General Overhead             0.600 * (L&O+M)




     CO2 14     Beer 15  Ethanol 16 Stillage 17    >Environ Evap >      >Boiler 18  Recycle 19  Cooling 20
                 452486                  452486     485969      466373       52999      233187      233187
                      0                       0          0                    6035
                      0                       0          0                       0
                      0                       0          0                   21046
                   5224                    5224       5224                    5224
                      0                       0          0                       0
                      0                       0          0                       0
                      0                       0          0                       0
                  22575                   22575      22575                   22575
                    449                     449        449                     449
                      0                       0          0                       0
                  20174       20073         101        101                     101
                      0                       0          0                       0
                      0                       0          0                     249
                   1045                    1045       1045                    1045
                      0                       0          0                       0
                      0                       0          0                       0
      20403           0                       0          0                       0
      20403      501953       20073      481880     515363      466373      109723      233187      233187
```

nvestment

```
XLABELS                 !    Project Code                 !                   !              !
X-----------------------!    Description                  !                                  !
X                       !    Project Name                 !                                  !
X                       !    Energy Source                !                                  !
X                       !    Technology                   !                                  !
X                       !    Application/Sector           !                                  !
X                       !    Location                     !                                  !
X                       !    Investor                     !                                  !
X---------------------------------------------------------!----------------------------------!
XCONSTANT PARAMETERS                              !Label!      Value      !      Units      !
X-------------------------------------------------!-----!-----------------!-----------------!
XAnnual Inflation Rate                            !h    >                 <                 !
XMarginal Income Tax Rate                         !T    !                 !                 !
XReal Cost Of Capital                             !kr   !                 !                 !
X                                                 !     !                 !                 !
XBase Year                                        !By   !                 !                 !
XDiscount Year                                    !Dy   !                 !                 !
XIn Service Year                                  !ISy  !                 !                 !
XLifetime                                         !n    !                 !                 !
X==========================================================================================
XCAPITAL                                          !Label!      Value      !      Units      !
X-------------------------------------------------!-----!-----------------!-----------------!
XInvestment Cost                                  !IC   !             121 !MM $             !
X                                                 !     !                 !                 !
XCapital Appropriations (Year -2)                 !Cy-2 !                 !                 !
XCapital Appropriations (Year -1)                 !Cy-1 !                 !                 !
XCapital Appropriations (Year 0)                  !Cy0  !                 !                 !
XDebt Financed Amount                             !df   !                 !                 !
XDebt Amortization Period                         !dap  !                 !                 !
XDebt Financing Interest Rate                     !dfr  !                 !                 !
X-------------------------------------------------!-----!-----------------!-----------------!
XDEPRECIATION                                     !Label!      Value      !      Units      !
X-------------------------------------------------!-----!-----------------!-----------------!
XDepr. Method (1=ACCA,2=Const,3=DB)               !Dm   !                 !                 !
XDepreciation (Year 1)                            !Dr1  !                 !                 !
XDepreciation (Year 2)                            !Dr2  !                 !                 !
XDepreciation (Year 3)                            !Dr3  !                 !                 !
XDepr. Period (Straight Line)                     !Dt   !                 !                 !
XDeclining Balance Rate                           !Dbr  !                 !                 !
X==========================================================================================
XEXPENSES                                         !Label!      Value      !      Units      !
X-------------------------------------------------!-----!-----------------!-----------------!
X                                                 !     !                 !                 !
X1st Input Energy (Wood)                          !L1   !           333.3 !MM Kg            !
XPrice of 1st Input Energy                        !Pie1 >            0.04 <$/Kg             !
XEscalation Factor (Real)                         !L1e  !                 !                 !
X                                                 !     !                 !                 !
X                                                 !     !                 !                 !
X2nd Input Energy (Electricity)                   !L2   !            82.8 !GWhr             !
XPrice of 2nd Input Energy                        !Pie2 >            0.03 <$/KWhr           !
XEscalation Factor (Real)                         !L2e  !                 !                 !
X                                                 !     !                 !                 !
X                                                 !     !                 !                 !
XO.& M. Costs                                     !M    >           16.60 <MM $             !
XEscalation Factor (Real)                         !Me   !                 !                 !
X                                                 !     !                 !                 !
X                                                 !     !                 !                 !
X                                                 !     !                 !                 !
X                                                 !     !                 !                 !
X==========================================================================================
XREVENUES                                         !Label!      Value      !      Units      !
X-------------------------------------------------!-----!-----------------!-----------------!
X                                                 !     !                 !                 !
XEnergy Produced (1st Output) (Ethanol)           !E1   !              91 !MM L             !
XAdjustment Factor (1st Output)                   !E1af !                 !                 !
XPrice of 1st Energy Output                       !Pe1  >            0.40 <$/L              !
X                                                 !     !                 !                 !
XEscalation Factor 1st Output (Real)              !E1e  !                 !                 !
X                                                 !     !                 !                 !
X2nd Output (Xylanase)                            !E2   !               0 !MM Kg            !
XPrice of 2nd Output                              !Pe2  >            0.12 <$/Kg             !
X                                                 !     !                 !                 !
XEscalation Factor 2nd Output (Real)              !E2e  !                 !                 !
X                                                 !     !                 !                 !
X3rd Output (Lignin)                              !E3   !               0 !MM Kg            !
XPrice of 3rd Output                              !Pe3  >            0.22 <$/Kg             !
X                                                 !     !                 !                 !
XEscalation Factor 3rd Output (Real)              !E3e  !                 !                 !
X                                                 !     !                 !                 !
X------------------------------------------------------------------------------------------
X                                                       \R
X                                                       /fwv(?)~RETASAVE~
```